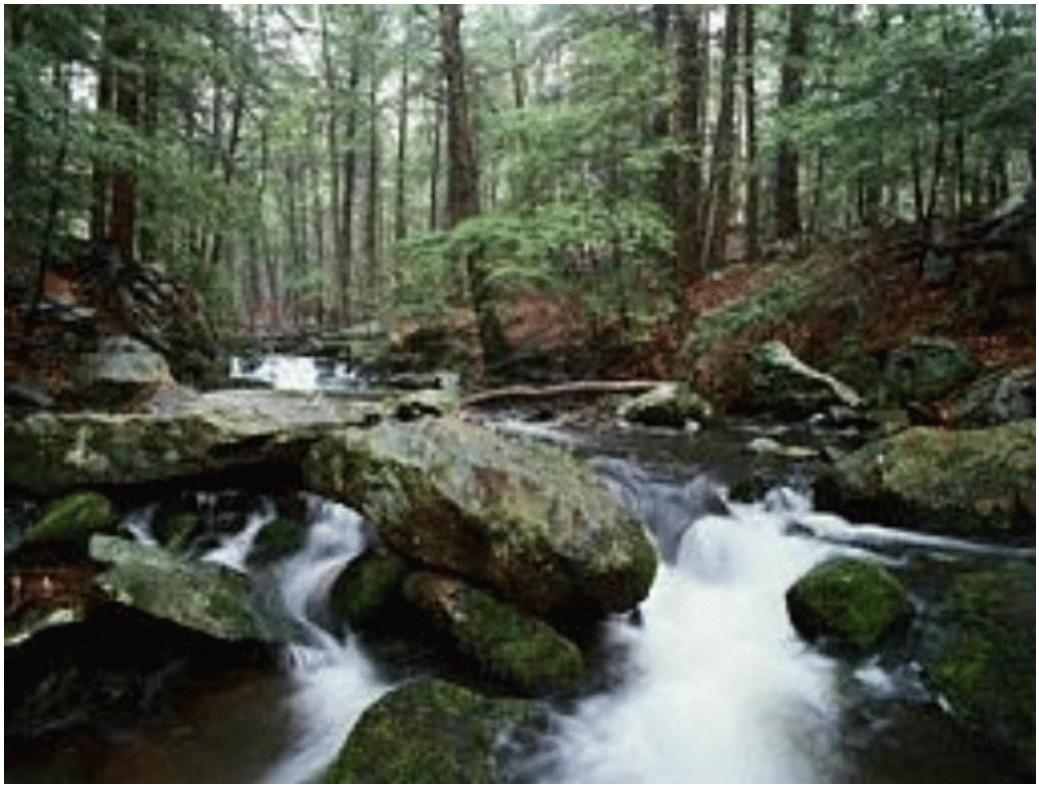
United States Environmental Protection Agency

EPA
May 29, 2003
Final Version

ECOLOGICAL RESEARCH MULTI-YEAR PLAN

Office of Research and Development



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Not Yet Externally Peer Reviewed

The Office of Research and Development's (ORD) multi-year plans (MYPs) present ORD's proposed research (assuming constant funding) in a variety of areas over the next 5-8 years. The MYPs serve three principal purposes: to describe where our research programs are going, to present the significant outputs of the research, and to communicate our research plans within ORD and with others. Multi-year planning permits ORD to consider the strategic directions of the Agency and how research can evolve to best contribute to the Agency's mission of protecting human health and the environment.

MYPs are considered to be "living documents." ORD intends to update the MYPs on a regular basis to reflect the current state of the science, resource availability, and Agency priorities. ORD will update or modify future performance information contained within this planning document as needed. These documents will also be submitted for external peer review.

PREFACE

The Ecological Research Multi-Year Plan was developed by the following individuals representing the Office of Research and Development, EPA Program Offices, and EPA Regions:

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1.0 INTRODUCTION

Future approaches to environmental problems will differ significantly from those of today. EPA's Ecological Research Program is designing fundamentally new tools and approaches that consolidate experience gained through Program Office successes and ORD problem-driven research, and take advantage of cutting-edge scientific knowledge and technical advances achieved across the academic, industrial, and federal research communities. The research program reflects the growing ethic of environmental stewardship and the need to increase the efficiency and effectiveness of environmental stewardship initiatives. In their implementation, these new approaches will be largely community and sector-based, place-based, and performance-based.

1.1 Background

Over the last decade, EPA has refocused its research program to better assess and compare risks to ecosystems, to protect and restore them, and to demonstrate progress in terms of ecological outcomes. EPA's Program Goal for its Ecological Research Program, *to provide the scientific understanding to measure, model, maintain, and/or restore, at multiple scales, the integrity and sustainability of highly valued ecosystems now and in the future*, lays out the vision for this outcome-oriented research program. To accomplish this, EPA has organized research to answer four critical scientific questions involving ecosystem Condition, Diagnosis, Forecasting, and Restoration and Management (text box 1).

Although these questions are relevant to the current approaches to environmental protection, the context of the questions is continually evolving in concert with changes in the accepted ecological protection paradigm. Current approaches have achieved great progress in reducing emissions of pollutants from point sources and waste disposal sites, and reducing mishandling of toxic or hazardous chemicals and pesticides. During the development of ORD's *Strategic Plan* (USEPA 2001), however, stakeholders expressed an expectation that future problems would be more subtle, potentially more far-reaching, and require very different solutions. Examples include the effects of global climate change, loss and destruction of habitat by urban sprawl and unsustainable rates of exploitation of natural resources, non-indigenous invasive species, non-point source pollution, and cumulative and interactive effects. Because of a long history of respect for private property rights in the United States and Constitutional constraints on the powers of the federal government, the solution to many of these problems cannot be centrally dictated from Washington, instead resting with state and local governments. The success of even the best-conceived of local actions is conditional, however, on the political, economic, and ecological framework imposed by actions at larger scales, ranging from international treaties to river basin management plans.

Box 1
Questions Driving Ecological Protection Research

Condition Research - What is the current ecosystem condition, what are the trends in condition, and what stressors appear to have been responsible for harm or deterioration?

Diagnosis Research - How do biological, chemical, and physical processes affect the condition of ecosystems, and how can we most accurately diagnose problems facing ecosystems?

Forecasting Research - How can we reliably predict ecosystem vulnerabilities to current development and resource exploitation practices, and the most probable responses of ecosystems to ameliorative best management and sustainable development strategies?

Restoration and Management Research - How can we most effectively control risks and manage to protect ecosystems and restore them once they have become degraded?

Consequently, the emphasis of this Ecological Research Program is to provide 1) monitoring for ecosystem condition that truly reflects the need for action and the scale of the problem, the causes of harm, and the success of mitigation and restoration efforts; 2) models and protocols that help diagnose causes of degradation to ecosystems and forecast future condition that are appropriate to the scale of the problem and incorporate scientifically defensible risk assessment techniques that can accurately quantify and compare current and future risks to ecosystems; and 3) management, restoration, and protection strategies that are cost-effective and stakeholder-driven. Achieving these goals will set the stage for ORD to achieve its strategic vision of "revolutionizing the use of science in environmental decision-making."

1.2 Progress to Date

ORD has already made substantial progress toward this goal using a variety of approaches. Cooperative efforts with States, regions, and other federal agencies have led to the adoption by many of the States of novel and efficient ecological monitoring designs developed and tested by the Environmental Monitoring and Assessment Program (USEPA 2002). ORD, working with academia, developed the first air quality model (Models-3/CMAQ) to use a "one atmosphere" approach to accurately simulate the interactions among many air pollutants, necessary to achieve truly cost-effective air pollution control strategies. ORD has produced the first national guidelines on assessing ecological risks (USEPA 1998). The STAR grant program has brought the most creative minds and the best ideas together to understand the integrated behavior of

watersheds and the importance of scale in understanding environmental problems and their solutions. ORD has undertaken region-specific projects from the Pacific Northwest to the tip of South Florida to better understand and seek solutions to place-based problems. This multi-year plan builds on those successes and others.

1.3 Overview of Long Term Goals

Box 2
Programmatic Goals for Ecological Protection Research

Condition:
The states and tribes use a common monitoring design and appropriate ecological indicators to determine the status and trends of ecological resources

Diagnosis:
Managers and researchers understand links between human activities, natural dynamics, ecological stressors, and ecosystem condition

Forecasting:
Environmental managers have the tools to predict multi-stressor effects on ecological resources to assess vulnerability and manage for sustainability

Restoration and Management:
Managers have scientifically defensible methods to protect and restore ecosystem condition

Building on ORD's *Ecological Research Strategy* (USEPA 2001), and ORD's earlier Ecological Research Strategy (USEPA 1998), we have adopted a number of Programmatic Goals (see text box 2) to move us toward the achievement of our overall Program Goal. We have expressed these goals as outcomes that reflect what ORD and our partners in the EPA Program Offices and Regions ultimately hope to accomplish. Even though they are beyond ORD's direct control, they are intended as a constant beacon to scientists and science managers as we pursue our more limited R&D mission. The goals are in the service of more reliable, more cost-effective ecosystem protection through the application of sound science, as reflected in the ORD strategic vision cited above.

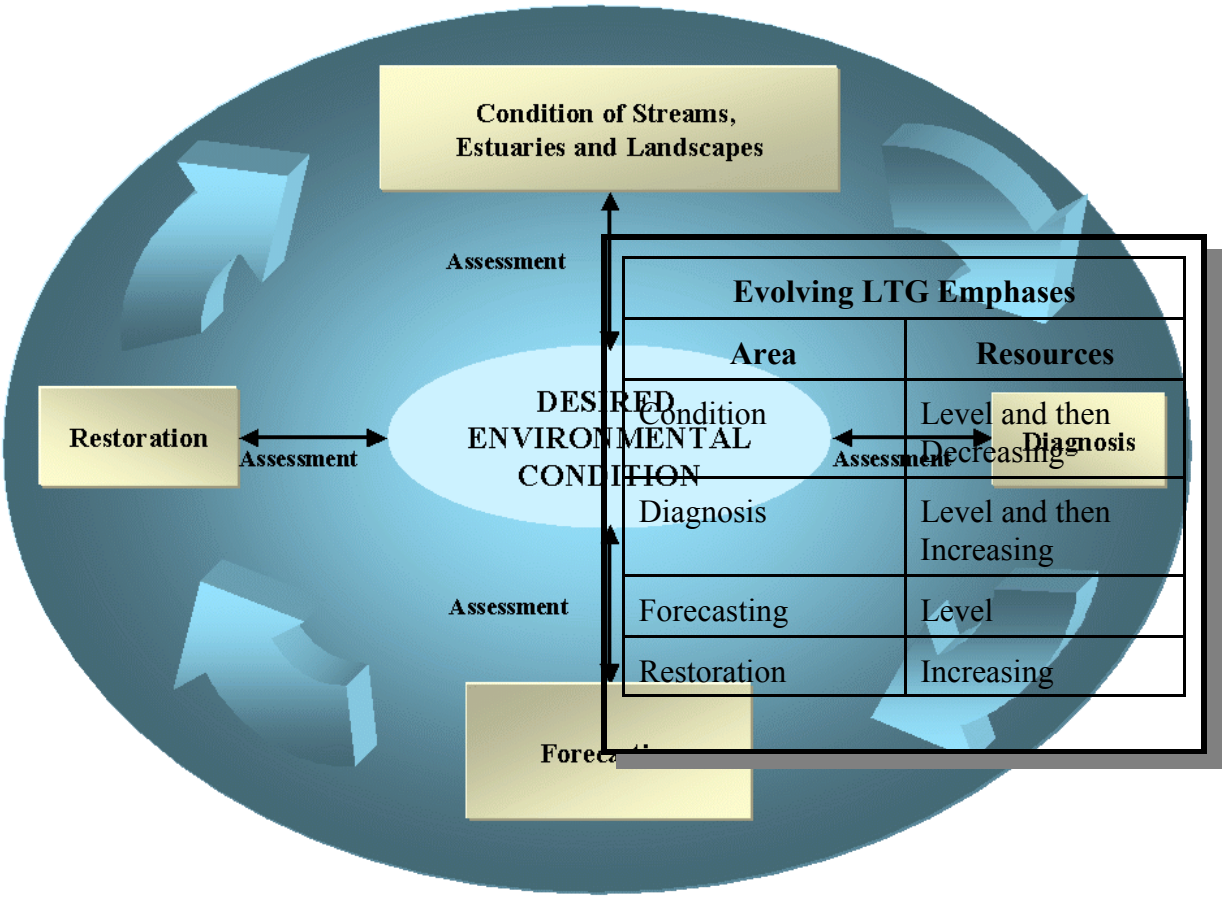
Each of the programmatic goals has subsidiary long-term goals (LTGs) over which ORD and EPA have more control – the long-term *research* goals. Each LTG is accomplished by achieving one or more Annual Performance Goals (APGs), each of which is marked by the production of one or more Annual Performance Measures (APMs). LTGs and APGs are expressed as outcomes – what we hope and expect will happen if we do our research and development in a way that environmental managers and the public find useful and compelling. The APMs are expressed as

products (reports, papers, databases, models, etc.) that are tangible measures of progress toward meeting our goals. Ultimately, it may be well to add customer surveys and other instruments to assess the degree to which we have been successful and to suggest additional technology transfer and implementation activities.

1.4 Overall Flow Diagram

It also is important to note the relationships among the four Ecological Research programmatic goals, and the relationship to problem-driven R&D (see Figure 1). The Ecological Research program has relied on first moving into a geographic area and characterizing the current status of ecological condition. Next comes diagnosis of the stressors most likely to be limiting to ecological health, and forecasting to determine the vulnerability and likely future status of the region, given the likely population growth and economic development. Then, we identify the most effective and efficient management and restoration strategies, and complete the cycle by assessing their impact on ecological condition. These program components are linked through assessment, which is conducted at all stages of the program. This allows the downstream research to build on data and analyses collected in the early stages. Finally, this innovative research contributes to better problem-driven research in support of Program Offices, which tend to be more single-media, single-regulation oriented due to the focused nature of the environmental statutes that guide EPA in its day-to-day operations.

At present *Condition* Research (EMAP) is focusing on wadeable streams in the West and on estuaries. An assessment of condition in the Mid-Atlantic is complete and vulnerability assessment (Forecasting) and restoration activities are underway. In FY03, the program will start a transition to the Mid-West and begin a focus on large rivers. *Diagnostic* activities develop relationships that are useful in establishing causality of existing conditions with enough robustness to serve as the basis for predicting trends, trajectories (forecasting) and responses to management actions (restoration, TMDLs). They relate status and trends to human and natural causes and consequences, identify information needed to reduce uncertainties, establish priorities for conservation and restoration of resources, and provide the basis for predicting the consequences of management actions. *Forecasting* activities build on these relationships to develop and evaluate science-based approaches for ensuring sustained productivity and health of ecological systems via projections of the consequences of current utilization and evaluation of



alternative future scenarios. *Protection and restoration* is moving from the traditional programs aimed at reducing emissions to restoring ecosystem function. *Assessment* must be done at larger scales than ever before; it is the glue that integrates the four steps into a complete analysis. As an agency, we must develop nationally-consistent policies and implement them at regional and state scales. Thus we must be concerned with the relative risk of many different stressors. More details on progress to date in each activity is included in the text that follows.

1.5 Evolution of the Program over Time

The Ecosystem Protection Research Program will evolve over time. As previously discussed, the Long Term Goal for Condition Research is to provide states and tribes with a common monitoring design and appropriate indicators to determine the status and trends of ecological resources. As this goal is achieved for important ecosystems (wadeable streams, large rivers, estuaries, wetlands and lakes), the program will evolve towards diagnostic research to develop

methods to determine causes of impairment, particularly in the context of spatially explicit assessments of multiple stressors. Molecular and computational methods are expected to play a significant role in diagnosis. Forecasting research is currently shifting from a focus on single-stressors to consideration of multiple stressors, and will begin including ecosystem resources and services as assessment endpoints. This will require consideration of socioeconomic aspects of assessment as stakeholder considerations are included. Restoration research currently focuses on riparian habitat in the Mid-Atlantic region and its role in mitigating contaminate transport to surface waters. Research to better quantify the benefits of restoration and develop cost/benefit ratios will increase over time. As the restoration program moves forward, there will be a move from understanding ecological processes to an increased emphasis on measuring the benefits of restoration. The timing of these changes are discussed in the individual sections that follow.

1.6 Resources

ORD's core Ecosystem Research Program comprises approximately $113M of ORD's $514M budget (about 22%) (FY03 President's Budget). Of this total, about half ($56M) is intramural costs – operating expenses, capital equipment, salaries and expenses, and travel for 228 scientific staff – and half ($57M) are extramural funds, including $22m in STAR grants.

2.0 CONDITION RESEARCH

2.1 Long-Term Goals

The Programmatic Goal for Condition Research is that:

> ***The States and Tribes use a common monitoring design and appropriate ecological indicators: to determine the status and trends of ecological resources.***

Within Condition Research there are several generic themes to be pursued in support of Agency needs, including:

- Ability to determine status and trends for all the nation's ecological resources, including identification of possible stressors leading to impairment at a broad scale;
- Development of defensible reference conditions for ecological resources, mechanisms for establishing reference condition in situations where they no longer exist, and mechanisms for establishing the expected conditions when remediation or restoration has occurred;
- Establishing the natural variability of ecosystems to establish better monitoring designs; ;
- Ability to determine the distribution of stressors which may lead to impairments at multiple scales;
- Improved determination of targeted monitoring locations to assist in the Clean Water Act 303(d) listing process;
- Developing sensitive and selective environmental indicators; and
- Developing statistical methods for design of surveys and interpretation of results

Eleven Subsidiary Long-Term Goals (Sub-LTGs) or general research themes contribute to the overall Programmatic Goal. A Proof-of-Concept Sub-LTG was delivered in FY03 which demonstrated the utility of several indicators and probabilistic designs to determine aquatic ecological conditions for the Mid-Atlantic Region (see Figure 2). The Sub-LTGs in the current MYP build on that Sub-LTG and can be categorized into two types, including 1) Methods needed to develop national monitoring designs in other geographic regions and 2) Developing or implementing monitoring frameworks to determine status and trends of ecological resources for various types of ecosystems in different geographical regions of the US. A chronological listing of the Sub-LTGs in the current MYP is illustrated in Figure 2 and summarized below:

FY06 Methods to effectively monitor trends in environmental condition with known confidence are available to EPA, the States, and Tribes

FY07 The States and Tribes use a common monitoring design and appropriate ecological indicators to allow a scientifically valid determination of the status and trends of their ecological resources, to improve the cost-effectiveness of their environmental programs and policies; and to allow their findings to be aggregated into regulatory decisions

FY07 Consistent land use/land cover databases are available for the U.S., as well as techniques to efficiently measure changes and understand the significance of changes over time

FY08 A national monitoring framework is available for estuaries that can be used from the local to the national level for statistical assessments of condition and change

FY08 A monitoring framework is available for streams and rivers in the Western U.S. that can be used from the local to the national level for statistical assessments of condition and change

FY09 A national monitoring framework is available for flowing waters that can be used from the local to the national level for statistical assessments of condition and change

FY09 A national monitoring framework is available for freshwater wetlands that can be used from the local to the national level for statistical assessments of condition and change

FY10 Development and application of methodology to utilize existing survey information to determine the likely locations of ecological condition of estuarine resources

FY12 Methods are available to integrate monitoring approaches and data across multiple scales, ranging from remotely sensed data over large regions to measures of chemistry and biology at individual sites

FY12 Implementation of a national monitoring framework for coastal ans stream ecosystems that can be used at the state, regional and national levels for statistical assessment of ecological conditions and change

FY15 A monitoring framework is available for Great Rivers in the Central US and the Great Lakes that can be used from the local to the national level for statistical assessments of condition and change

The APGs and APMs associated with each of the Sub-LTGs needed to achieve each Sub-LTG and, ultimately, the Programmatic Long-Term Goal are described in Appendix Table 1.

Monitoring of ecosystem condition is an important tool used to identify environmental problems, and to measure the efficacy of the more than $1 trillion per year spent on environmental protection in support of the Government Performance and Results Act of 1995. Monitoring involves developing cost-effective indicators that capture the condition of the environment, and capture the actual causes of harm (e.g., exposure to pollutants). Equally important is the development of cost-effective sampling designs that allow the measurements to be extrapolated

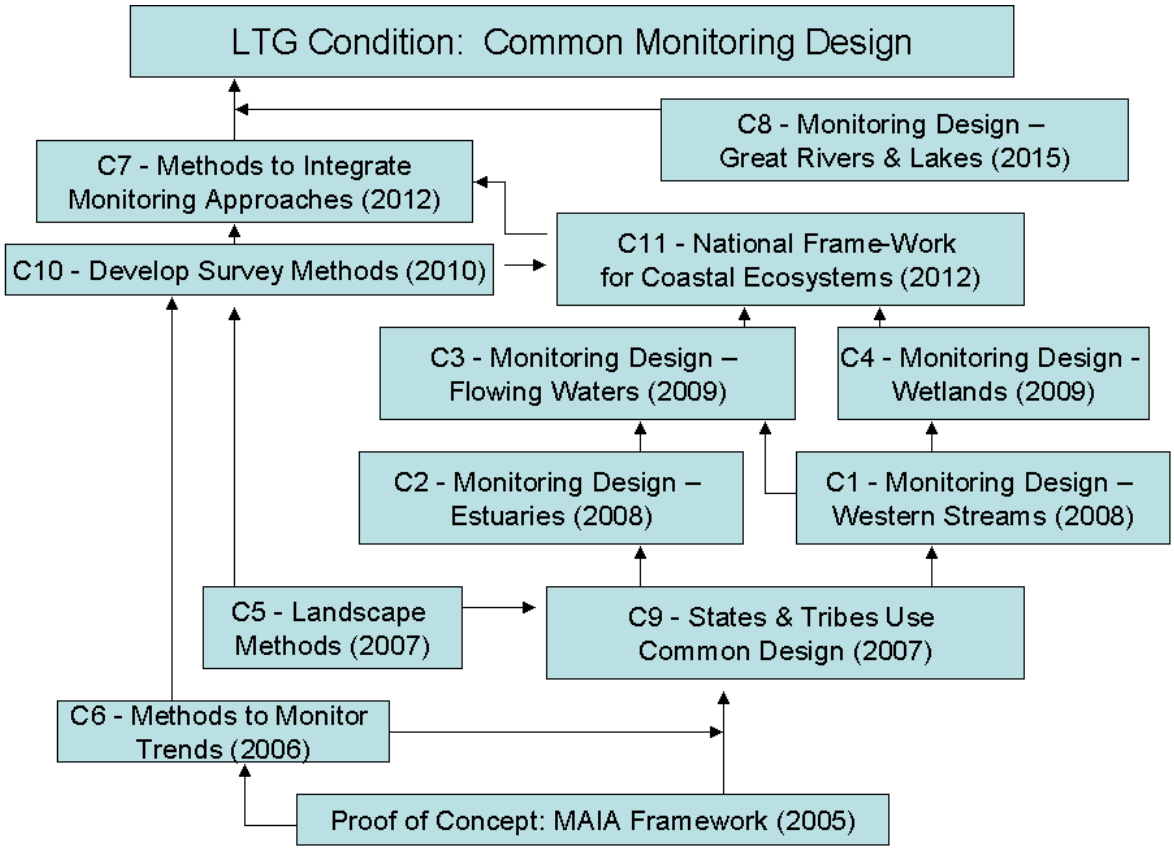


Figure 2 Flow Chart for Conditions Research Sub-LTGs

in a scientifically defensible way to times and places where measurements were not made.

Finally, it is important to meaningfully link measurements made over large areas (e.g., satellite-based images of land use patterns that do not change significantly over months) to measurements made of the physical structure, chemistry or biology of a point in an ecosystem at a particular time. There also are scientific issues relating to ecosystem classification and reference conditions that must be resolved in order to develop a comprehensive ecosystem monitoring approach for the nation. For our new monitoring technology to be successful, it must accepted and used routinely by State and Tribal agencies.

For example, it is cost-prohibitive to physically monitor all the waters in the country, so most states monitor a subset of their waters. However, most monitoring is not currently done in a way that allows for statistically valid assessments of water quality conditions in unmonitored waters (GAO 2000). States thus cannot adequately measure the status and trends in water quality in all their waters, although required by section 305(b) of the Clean Water Act. This also reduces the States' and EPA's abilities to carry out key management and regulatory activities. These data gaps are particularly serious for non-point sources, which are widely held to contribute to the majority of the nation's water quality problems (GAO 2000).

To address this problem, in 1989 ORD began to develop scientifically valid sampling designs for estuaries, streams, lakes and forests in the Environmental Monitoring and Assessment Program (EMAP). ORD also undertook, with its Federal partners, the development of the Multi-Resolution Land Characteristics (MRLC) database, the first nationally consistent digital database at 30 m resolution for the years 1992-93. In addition, ORD's STAR grant program invested in the development of indicators, while intramural research in ORD has a long history of developing monitoring science to establish patterns and trends in air pollutants, including acid deposition.

At the heart of our approach to monitoring condition of ecological resources is a scientifically defensible, statistically rigorous sampling design. This statistical (or probability) sampling framework provides the basis for estimating resource extent and condition, for characterizing trends, and for representing spatial pattern, all with a known confidence level. Pilot studies are undertaken to reduce scientific uncertainties in our approaches and to demonstrate the applicability to States, Tribes and EPA Regions. EMAP began its pilot studies of estuaries, streams and forests in the Mid-Atlantic region. With condition of aquatic ecosystems in the Mid-Atlantic established, ORD has expanded its research scope in this area beyond monitoring to include diagnostic and forecast modeling, and management and restoration research (discussed below). Projects applying the monitoring framework at smaller scales are undertaken each year by the ten EPA regions, working with ORD in the Regional EMAP (R-EMAP) program. The R-EMAP studies allow us to test our approaches in diverse geographic areas, engage additional States, and transfer our technologies, while helping to solve local problems. Ultimately, we expect that these sampling designs will be adopted by the states to support their semi-annual 305(b) reports and 303 (d) listings.

Under the Clear Water Act, each State must characterize the condition of State waters (biannual 305(b) reporting) and periodically identify and list waterbodies within its boundaries that fail to meet its standards of water quality (303 (d) listing), submit the list to the Agency, and establish Total Maximum Daily Loads (TMDLs) for each impaired waterbody. Currently, there are no standard, scientifically defensible, cost-effective integrative, monitoring procedures for meeting either requirement of the Clean Water Act.

For a State to produce an integrated monitoring approach, a first prerequisite is that it must be able to determine the condition of its aquatic resources within its boundaries without bias and with known confidence. ORD research on environmental indicators and probabilistic sampling (survey) designs is providing the States with a scientifically-defensible means of characterizing the overall condition of stream/estuarine resources for 305(b) reporting. However, in these surveys intended for 305(b) reporting, there is no explicit determination of the actual waterbodies impaired to allow for listing under section 303(d).

The State's 303(d) listings are critical, as TMDLs are developed for these sites. Estimates of the cost of implementing measures for the TMDL program range between $900 million and $4.3 billion annually. Thus, an approach to determine overall accuracy of the state's current 303(d) listings must be an initial priority. Over-representation on the list could lead to wasted state financial resources; under-representation could lead to impaired environmental conditions.

ORD's Condition Research program over the next 10 years will focus on achieving the long term goal of "states using monitoring designs and indicators which optimize for assessment of condition, identification of impaired water bodies and determination of probable cause of that impairment". The output of an integrated condition monitoring process (Figure 1) provides overall assessments of condition for 305(b) and 303(d). The output from condition assessments provides the input for concurrent research on the diagnosis of the causative agent(s) of impairment, predicting risks involved with the impaired sites, and developing remediation methodologies.

The critical steps/path to achieving this goal are:

1. Development and technology transfer of sampling designs and indicators for assessment of condition
2. Development and technology transfer of methods and models to identify waterbodies/assessment units with high likelihood of impairment
3. Development and institutionalization of sampling designs and indicators which build upon the characterization and modeling efforts while providing the additional information needed for confirmation of impairment and cause

The survey data and comprehensive land use data can then be used to develop; 3) models which predict the likely locations of impairment, resulting in; 4) preliminary assessment of likely areas of impairment. The conceptual outputs shown in Figure 1 are examples of individual products in different places; obviously, a full exercising of the framework would result in 1-3 in one place for 1 or more suites of "impairment" based on numerous criteria.

ORD Research on Conditions figures to play a major role in the development of the State of the Environment Report. In 2001, the Administrator of EPA directed the Office of Environmental Information to partner with the Office of Research and Development to lead an agency-wide "Environmental Indicators Initiative" to gather and develop information about the current state of the environment in a fashion that would enable informed, strategic decisions in the future. The indicators work that is supported by ORD Conditions Research will be important in helping develop an inventory of environmental indicators that will allow the Agency to report on the environment, as well as identify data gaps and guide future research. Results on reference conditions in specific ecosystems at various geographic locations will be important to help the Agency identify priorities, focus on areas of greatest environmental concern and work to manage measurable results.

2.2 APGs and APMs

As illustrated in Figure 2, the overall Programmatic Goal of Conditions Research is that states and tribes will use a common monitoring design and appropriate ecological indicators to determine the status and trends of ecological resources. The overall strategy of the current MYP on Conditions Research is two-fold, including 1) developing the appropriate tools and methods to be used with probabilistic study designs and 2) developing national frameworks for specific ecosystems in various regions of the US. Research on Conditions described in this MYP builds on results finalized in a Sub-LTG in FY03 in which it was demonstrated that probabilistic designs using selected bioindicators could be used by states to determine reference conditions and effects of stressors on ecosystems in the Mid-Atlantic region of the US.

By FY06, methods will be developed to monitor trends in estuarine environmental conditions with a known degree of confidence, including the use of probability sampling for detecting trends in ecosystems and the development of new and improved ecological indicators.

By FY07, the next set of consistent land use/land cover databases will be available for the US, as well as techniques to efficiently measure changes that have occurred in ecosystems over time. Research in this area will result in a national assessment of the consequences of landscape change. Landscape ecology will play an increasingly important role in environmental monitoring. Landscape ecology reflects the importance of pattern in the landscape in providing critical habitat for wildlife, affecting water quality and biota in lakes, streams, and estuaries, and

influencing the quality of life for human communities. ORD completed a development and accuracy assessment of the MRLC based on early 1990s data in 2002. In 2003, ORD will begin the next important step, which is to identify the most cost-effective ways to measure changes in important landscape indicators (patterns that are related to environmental quality), to develop a second MRLC database from the early 2000s, and to assess the rates and environmental importance of landscape changes over the past three decades. This assessment will be pivotal in understanding the importance of landscape change as it affects and constrains the management of non-point-source pollutants in the 303(d) process, and as such is critically linked to LTG 2 of the Water Quality MYP, and in informing decisions about smart growth by state and local governments.

Appropriate monitoring methods to evaluate ecosystem conditions will be sufficiently developed that by FY07, many states and tribes will be using a common monitoring design and appropriate ecological indicators to determine the status and trends of the aquatic resources and be used in decision making. Starting in FY08, Conditions Research will begin development of several national monitoring design frameworks for specific ecosystems in various geographical regions of the US. For example, the EMAP Western Pilot will encompass the twelve western states in EPA's Regions 8, 9 and 10. This is a vast area of the country with great ecological variability, which allows researchers to test the generality of the designs and indicators in highly complex environments. The focus of the Western Pilot will be on the condition of streams and estuaries and on the landscapes that influence these ecosystems. By FY08, this research will establish baseline conditions of Western streams using probabilistic survey designs, develop probabilistic design framework allowing for the aggregation of data from several Western states, and establish the condition of Western aquatic ecosystems.

The National Coastal Assessment (NCA) is a national ORD effort to demonstrate a consistent, integrated, probabilistic monitoring effort to establish the baseline condition of the U.S. estuaries and coastal systems. ORD is partnering with EPA Regions, EPA's Office of Water, 24 marine coastal States and Puerto Rico, USGS, and NOAA to conduct the sampling of estuaries. A minimum of 50 locations are being sampled in each marine coastal State and Puerto Rico. From this we will develop a national report on the condition of the Nation's estuaries, as well as reports on the condition of the estuaries in each of the individual States and Puerto Rico. STAR has invested in 5 coastal research centers, the Estuarine and Great Lakes Program (EAGLE), which cover the major bio-geographical regions of the coastal US and will develop the next generation of condition and diagnosis indicators. In 2002, we began our assessment of the condition of the near-shore coastal environments in the Western continental U.S. to complement EPA's ongoing efforts to improve beach monitoring, in support of CWA 403(c), 301(h), and 316 (a) and (b) programs. As we complete the initial phase of the NCA, we will have sufficient information on selected estuaries to begin examining change detection and, subsequently, trends in condition. However, in 2008, there will be sufficient data on estuaries sampled early in EMAP to evaluate the power of the survey design for these systems to detect change in condition and,

subsequently, trends across most US estuaries. FY08, this research will provide the public with a reliable picture of the condition of the nation's estuaries, as well as information on conditions in near-shore coastal ecosystems. Research to develop a national framework for estuaries will also include research to determine the distribution of existing and the extent of invasive species in selected aquatic ecosystems. Results from the Western Pilot and National Coastal Assessment will be used to guide the development of monitoring frameworks for other aquatic ecosystems. By FY09, research will result in a framework for monitoring conditions on flowing waters, as well as a framework for the assessment of freshwater wetlands.

Prior research on coastal systems will lead to the implementation of a national monitoring framework for coastal ecosystems that can be used at the state, regional, and national levels for assess ecological conditions and change to stressors. By 2012, this research will results in a report on all of the coastal resources in the US, including estuaries, coastal wetlands, and offshore aquatic ecosystems, resulting in a National Coastal Condition Report for the US that integrates all available information from various ecosystems in the US.

Parallel to research on conditions of coastal and stream ecosystems will be the development of capability to assess other, but dissimilar systems, such as the Great Rivers in the Central US and Great Lakes. This research will develop a scientifically-defensible sampling and analysis design to monitor ecological condition of the Missouri, upper Mississippi, and Ohio Rivers. By FY15, Conditions Research will have developed a monitoring program for the Missouri and upper Mississippi Rivers of the Central Basin, develop methods to establish conditions for Great Rivers in the Central Basin, developed a monitoring framework to enable an integrated assessment of the Great Lakes aquatic ecosystem, and developed probabilistic monitoring framework for Great Rivers and Lakes in the Central US. The STAR program is also supporting complementary research on indicators for the Great Rivers in the Central US and Great Lakes through a research center known as River-EAGLE.

It is recognized that it is critical to integrate monitoring data over a variety of scales. For example, regional surveys, while necessary to understand progress toward environmental goals, do not provide the information needed to understand exact causes and remedies for individual lakes and watersheds. Landscape data must be linked to regional survey data, and to targeted data on point sources and fish and invertebrate communities, to inform watershed management strategies that result in attainment of state water quality goals under the 303(d) listing process. Projects under this area, which reflect the cutting edge of science, are largely funded under the STAR grant programs. RFAs include the use of scaling theory in linking data at different time and space scales, ecosystem classification research needed to better resolve the roles of human disturbance versus natural factors in patterns of biological indicators, and the integration of landscape ecology with biological monitoring in EMAP sampling designs. By 2012, research will result in development of scaling protocols for linking index sites, geographic surveys, and landscapes in a multi-tier design; establish monitoring protocols for regional and state aquatic

ecosystems; develop appropriate new ecological bioindicators; establish linkages between terrestrial and aquatic ecosystems; and develop approaches for integrating 305(b) and 303 (d) up to the regional level.

ORD's bioindicator research, important for the entire ecological research effort, will be strongly supported by the STAR program. The premise of this research is that biological monitoring is a direct means of assessing ecological condition which could lead to diagnosing causes of harm to ecosystems. For example, chemical grab sampling of aquatic systems, while often less expensive per sample than biological measurements, often fails as a surrogate for biological measurements because of our incomplete understanding of cause and effect, or because the cause of harm (e.g., a pollutant or pollutants) is not present at the time of sampling. Biological indicators measure condition more directly, integrate the effects of periodic exposures to multiple pollutants, and provide a more accessible and understandable tool to communicate with stakeholders and the public. Research in this area will focus on measures of community structure and genetic markers to determine and diagnose the cause of poor condition in aquatic systems. This is an important factor for the States and Tribes in deciding what implementation strategies are needed to meet designated uses in water bodies.

It is important that research on Conditions establish linkages to other components of the MYP. By 2010, research will lead to the development and application of methods to utilize existing monitoring data to diagnose the ecological condition of estuarine resources. This research will initially explore available approaches to diagnose ecological conditions of unsampled estuarine resources based on landscape data and probabilistic surveys. This effort will be followed by research to assess and diagnose conditions of US estuarine ecosystems using pilot surveys and models.

2.3 Summary of non-EPA Ecological Condition Research Supportive of the Ecological Research Program

Under the auspices of the White House Office of Science and Technology Policy, the Committee on Environment and Natural Resources (CENR) formed the Environmental Monitoring Team in 1995. The Environmental Monitoring Team took the crucial step of bringing federal agencies together to shape a national framework for integration and coordination of environmental monitoring and related research (CENR 1997). The framework calls for all environmental agencies to merge efforts in forming a national monitoring and research network which will link remote sensing, regional surveys, and intensive, multi-resource monitoring areas. Also, this framework unites the respective agencies in achieving a common national goal of understanding and managing our ecological systems for their sustained use and enjoyment. Their framework was very similar to ORD's multi-tier monitoring approach. The interagency nature of the framework allowed ORD to focus on priority EPA needs. Because States, Tribes, and EPA have

statutory responsibilities within the Clean Water Act to monitor the surface waters in their state, tribal lands, and in the country, respectively, and because these waters integrate the atmospheric, landscape and upstream inputs, aquatic ecosystems were chosen as ORD's initial focus.

In the National Coastal Assessment, EMAP partners with EPA Regions, the Office of Water, resource agencies in the 24 coastal states, NOAA and USGS to conduct sampling. NOAA is participating primarily through its National Status and Trends Program. They are participating in the planning and implementation of the survey in the southeastern US. NOAA is conducting intensified sampling in selected western estuaries that are being integrated into the EMAP Western Pilot estuarine sampling, and USGS/BRD is conducting intensified sampling in western wildlife refuges with a focus on contaminant levels and effects. EMAP will integrate their sampling in coastal areas as an intensification in the Western Pilot design. NOAA/NASA/EPA are providing joint grant support to a network of 11 coastal index sites around the country in order to develop indicators and conduct process and mechanistic studies. Research in the Central basin of the US involves collaborations with the Army Core of Engineers and USGS, as well as the multi-state River Basin Association.

EMAP has worked with USGS- EROS Data Center to develop the MRLC data base for landcover from the 1992-3 for the country. This is being used extensively in characterizing landcover/land use in the Western Pilot. EMAP initially worked with USGS-NAWQA in MAIA to link our EMAP survey data with their more deterministic temporally intensive index site efforts. Models developed at NAWQA sites may allow us to spatially interpret their predictions over a larger regional scale (e.g., loading models). We are continuing this process in the Western Pilot.

The U.S. Forest Service Forest Health Monitoring (FHM) program uses an EMAP probabilistic design. ORD has used FHM data in the Mid-Atlantic, and the Western Pilot will link its efforts in riparian areas with FHM as they move into the West. ORD will also continue to work on wetlands in cooperation with the BRD National Wetlands Inventory.

3.0 DIAGNOSTIC RESEARCH

Understanding the causes of degraded and impaired ecological conditions is a central component of maintaining and restoring desired environmental conditions. Reflecting this, and building a link between research efforts to understand ecological condition and research efforts focused on restoration, is the long term goal for diagnostics. This long term goal is stated as follows:

> *Manager and researchers understand links between human activities, natural dynamics, ecological stressors and ecosystem condition.*

Research on environmental and ecological diagnostics is conducted as separate components in the ecological research multi-year plan and the multi-year plan for water quality. Three main themes are represented in the research included in the ecological research multi-year plan: 1) Identify causes of degraded and impaired conditions identified with monitoring and assessment approaches developed as part of research on ecological conditions; 2) Better understand the relationships between environmental stressors and ecological resources and services of interest, and; 3) Develop protocols and decision support tools to assist environmental managers with diagnosing and managing environmental stressors.

Diagnostics research is organized into six sub-long-term goals, representing work to be completed in the 2006-2009 time-period. The relationships between these sub-long-term goals are shown in Figure 3.

3.1 Identifying Causes

Research efforts focused on identifying the causes of degraded and impaired conditions reflect a strong initial emphasis on aquatic ecosystems, especially streams, rivers, and estuaries. Diagnostics research for wetland habitats is smaller and less developed, but is likely to be an area of increased attention in future years.

Diagnostic research seeks to link specific effects on ecological resources to specific environmental stressors. For ecological resources, the ecological endpoints of concern tend to be the ecological indicators and indices developed for monitoring and assessing the condition of aquatic systems. These endpoints typically represent some aspect of ecosystem structure as reflected in fish, benthic, epiphytic, and pelagic communities. The environmental stressors considered include conventional stressors such as chemical contaminants, nutrients, pathogens, and sediments. Increasingly, however, there is greater emphasis on considering specific biological stressors such as habitat loss and the impacts of non-native, invasive species.

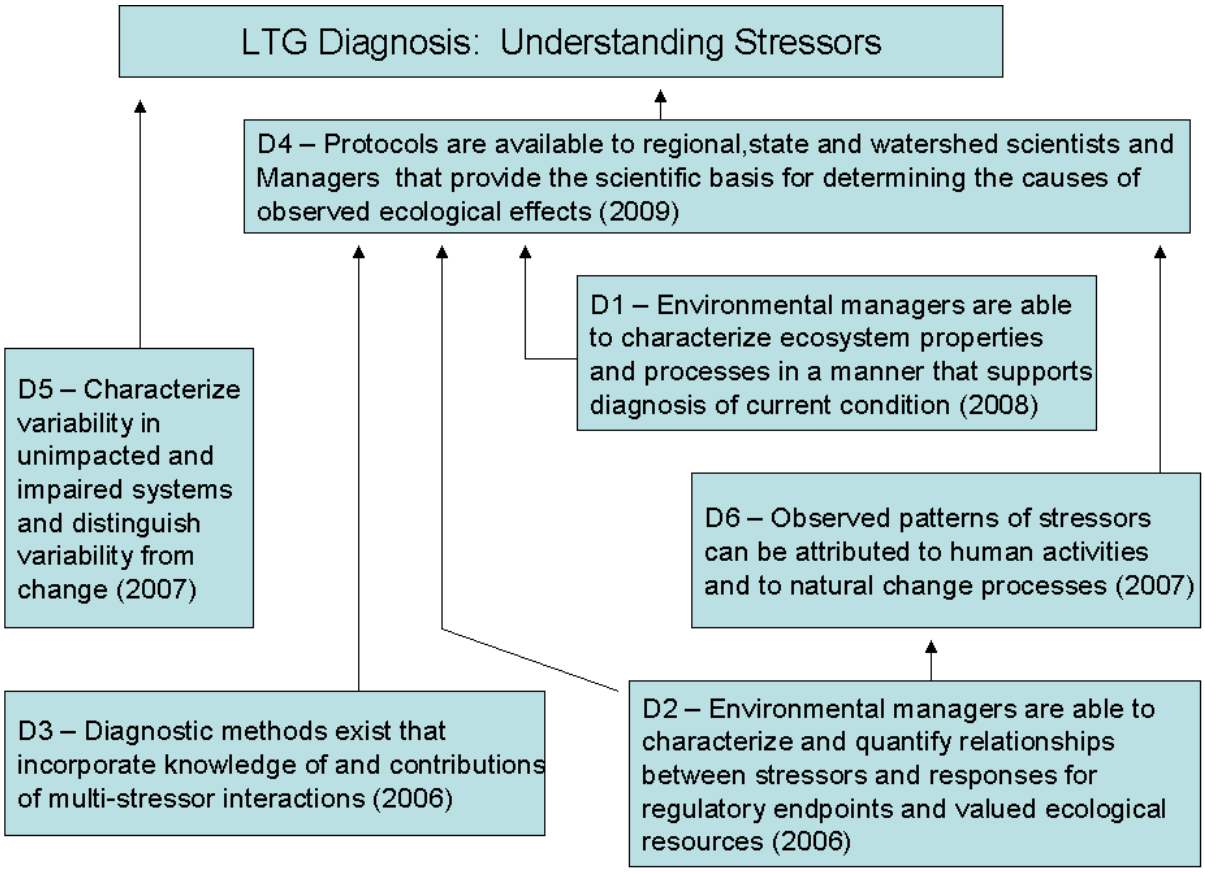


Figure 3 Flow Chart for Diagnosis Research Sub-LTGs

Diagnosis of the causation of impaired condition presumes the ability to distinguish between natural ranges of variability and anthropogenic impacts; thus characterization of natural variability is a essential component of the diagnostic research program. The diagnostic tools may be based upon semi-empirical relationships between landscape conditions and ecological indicators or on a series of mechanistic relationships. Although the former can be derived from monitoring data and landscape characterizations that are now available nationwide, the robustness of those relationships across a range of biophysical conditions and the suitability of such relationships for predicting responses to management actions still needs to be tested. Thus, a critical element of diagnostic research is the development and validation of landscape models in conjunction with mechanistic explanations of causation.

3.2 Stressor-Response Relationships

Another thrust of diagnostics research is to improve understanding of the relationships between environmental stressors and ecological receptors and services of interest. This research on stressor-response relationships is being conducted for both single and multiple stressors, and at various scales ranging from genetic markers to landscapes.

Diagnostic Research includes the development of scientifically valid approaches for linking environmental conditions characterized at the landscape level with effects on populations of wildlife and aquatic species. Research in this area will improve the ability to perform retrospective (diagnostic) and prospective (forecast) assessments of risks to biota as determined by the spatial distribution of habitat quality and stressors (e.g., toxic chemicals, nutrients, disease, invasive species) in the landscape, in accordance with EPA's ecological risk assessment guidelines. Three major research objectives include: 1) developing approaches to characterize landscapes (and ecosystems s) in terms of habitat quality and stressor distributions using remotely-sensed information and data from monitoring efforts; 2) developing mechanistically-based approaches for extrapolating biological response across species, chemicals, time, space, and response endpoints; and 3) developing stressor-response relationships and modeling approaches for predicting population-level health as functions of habitat quality and stressor distributions. These approaches will have direct applicability in risk management efforts to remediate habitats to ensure population sustainability, and will serve as the foundation for addressing individual programmatic needs throughout the Agency.

A shift of emphasis from point-source discharges to landscape- and watershed-scale processes as causes of impairment has increased the need for biological indicators and metrics as the preferred method for determining ecosystem condition. For example, diagnostic activities for water quality impairment have shifted from one-dimensional chemical measures of water quality to integrative measures of ecological condition. APGs in this plan have been developed in coordination with the Water Quality Multi-Year Plan to develop diagnostic methods for causal linkages of biological indicators and single- and multiple-stressor exposures in freshwater and marine systems. In addition to being of diagnostic value, these relationships also serve as indicators of ecosystem response to future scenarios and restoration actions; the plan calls for incorporation of the stressor-indicator relationship into models and decision-support tools.

Diagnosis research thus includes fundamental process research to address uncertainties in distributions of single-stressors and interactions among multiple stressors, including "traditional" (e.g. toxics, nutrients) and nontraditional stressors. Improved knowledge of the biogeochemical processes controlling nutrient processes in watersheds is critical to watershed approaches to TMDLs, as well as to understanding how watersheds will respond to likely future scenarios, including restoration actions.

3.3 Integration of Molecular Biological Approaches into Diagnostic Research

Three of the Sub-Long Term Goals under Diagnostic Research (D1, D2, D4) are addressed substantially by molecular biological research. Unprecedented advances have occurred in the life sciences over the last years. The new data and technologies from these advances are providing extraordinarily rapid and detailed characterizations of the molecular processes underlying aquatic ecosystem phenomena. These phenomena range from gene flow within species measured at the regional scale and fate, transport and uptake of specific xenobiotics within mixtures into aquatic organisms measured in near-real-time. Two main molecular biological research areas contribute to the Diagnostic Research Goals: development of molecular diagnostic indicators and development of indicators of species genetic diversity.

Molecular diagnostic research will provide the environmental science and risk assessment community with advanced molecular biological indicator methods, complete with validation studies and guidance for their application. These methods will employ DNA microarray technology, focusing on species of relevance to aquatic ecosystem risk assessment. The application guidance will include linkage of the earliest recognizable signatures of exposure (changes in tissue gene expression) to (1) adverse effects, lesions and altered organism and population function, (2) output of environmental chemical transformation and physiologically-based pharmacokinetic models and (3) comparative exposure assessments of organisms in regional field studies. Perhaps most significantly, these molecular biological diagnostic indicators will open the door to an understanding of the interactions which occur at the subcellular level when organisms are exposed to mixtures.

A completely developed indicator of genetic diversity will bring significant new data to the assessment of the integrity of aquatic resources and the sustainability of fish communities. These new data will be used to help characterize (1) appropriate ecological units (biological populations) for assessment of fish communities; (2) the inherent vulnerability of aquatic species to further exposure to stressors; (3) the relationship between genetic diversity and environmental condition; (4) temporal trends in the condition of fish populations; and (5) linkages between landscape-level stressors and population-level outcomes for aquatic organisms. Coupling of these molecular genetic data with quantitative environmental data and landscape data gathered through EMAP and other initiatives will allow powerful inferences to ecological condition and population responses to environmental stressors.

3.4 Protocols and Tools

The final component of the diagnostic research efforts represented in this multi-year plan integrates knowledge of stressor diagnostics and stressor-response relationships into protocols and decision support tools that can be used by environmental resource managers to identify potential causes for degraded and impaired ecological resources.

4.0 FORECASTING RESEARCH

ORD's Ecological Forecasting Research activities are designed to address scientific uncertainties associated with lack of fundamental knowledge, and to develop core predictive capabilities that support high priority activities designated by program offices, regions, and other clients. High priority research in this area includes work not addressed by other single-media goals (e.g., multimedia modeling), exploratory research that provides the theoretical and empirical relationships for forecasting, and development of robust and flexible modeling structures, including supporting data, that can be applied to multiple stressors at multiple scales.

Forecasting Research priorities are established under two guiding principles:

- selection of those problem areas that directly support programmatic goals and regulatory mandates while advancing the Agency's core scientific capabilities, and
- selection of those problem areas that build active collaborations with external research, including that funded by NCER and other Agencies, to maximize the incorporation of scientific advances into Agency programs

These research activities have been developed through ongoing consultations with EPA Program Offices, Regions, and interagency working groups.

The *diagnostic* activities described in the previous section develop relationships that are useful in establishing causality of existing conditions with enough robustness to serve as the basis for predicting trends, trajectories (forecasting) and responses to management actions (restoration, TMDLs). They relate status and trends to human and natural causes and consequences, help identify information needed to reduce uncertainties, establish priorities for conservation and restoration of resources, and provide a basis for predicting the consequences of management actions. *Forecasting* activities build on these relationships to develop and evaluate science-based approaches for ensuring sustained productivity and health of ecological systems via projecting the consequences of current utilization and evaluating alternative future scenarios.

The emergence of multi-stressor impacts and environmental stressors that cross administrative and organizational boundaries has led to "place-based" approaches to environmental decision making. Such approaches require the development of tools that support the identification of patterns at various spatial and temporal scales and that accommodate interactions between multiple stressors and higher level biological indicators based on a sound understanding of ecosystem processes. Thus, forecasting research activities reflect the importance of geographic context and the need for decision support frameworks that incorporate a wide variety of data and modeling approaches and tools. Moreover, in order to test the connectedness and completeness of the stages of ecological assessments outlined in the introduction of this plan, it is important

that a substantial portion of the research be carried out in the same geographic setting. Thus, although forecasting capabilities will ultimately have national applications, a number of the outputs described in this section are designed to consolidate and link the nearly-completed Mid-Atlantic Integrated Assessment of condition and the Regional Vulnerability Assessment for the Mid-Atlantic. Activities are proposed for other regions where approaches and methodologies for additional resources, such as large rivers or arid regions, are required.

The sum of these considerations, then, led to the adoption of a programmatic goal for ORD forecasting research responding to the requirement to project trends and to predict the outcomes of management actions for human and ecological endpoints of concern:

> **Environmental managers will be able to predict in a scientifically sound manner multimedia, multi-stressor outcomes of alternative management practices for valued resources, including uncertainties in predictions and sensitivity to change**

or, as captured in the formal outcome-oriented "Long-Term Goal" (LTG):

> **Environmental managers have the tools to predict multi-stressor effects on ecological resources to assess vulnerability and manage for sustainability.**

Predictive capability, created by combining theoretical understanding of ecological systems and knowledge of present conditions and stressors, is the essential bridge to defensible analysis of the effects of alternative management strategies. This capability gives environmental managers an objective and reliable way to sort through complex potential outcomes and consider tradeoffs among multiple objectives, so they can recommend approaches that balance stakeholders' competing interests and protect the longer-term integrity and sustainability of ecological systems and ecosystem services.

The inherent complexity of ecological systems mandates the use of numerical models, ranging in complexity from empirically-based correlations to process-based dynamic simulations. Aquatic ecosystems integrate atmospheric, terrestrial, landscape, groundwater, and upstream influences, so even focused comprehensive aquatic modeling studies typically require multiple models and types of data sets, which can be difficult to properly manage, integrate, and evaluate (Figure 4). To successfully satisfy the long-term goal for multimedia issues identified by clients, research is being conducted both on models and on the supporting tools required to assist with model management, integration, and evaluation. In addition to work directly sponsored under this Ecological Research Program, these research activities take advantage of, and contribute to, complementary activities within the problem-driven research programs.

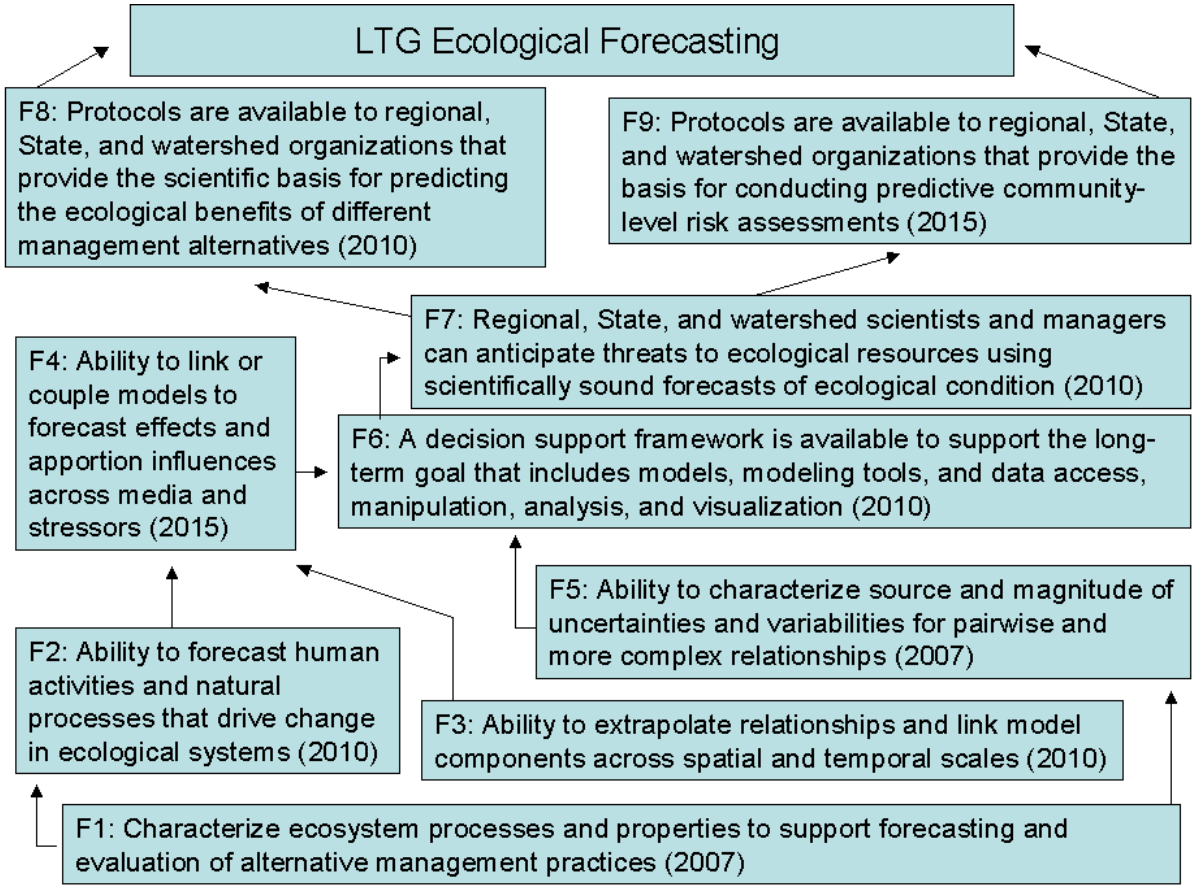


Figure 4 Flow Chart for Forecasting Research Sub-LTGs

To pick a single illustrative example, the Water Quality MYP outlines a watershed approach for translating water quality standards into point- and non-point-source load reductions needed to achieve healthy watersheds. EPA encourages watershed approaches in establishing TMDLs (Total Maximum Daily Loads) so that cumulative and synergistic effects can be given careful consideration. Coordinated TMDLs targeted to clean up an entire watershed can be expected to be both less expensive and more effective than an array of single-stressor TMDLs designed in isolation. At the watershed level, TMDLs can also help structure innovative solutions, such as nutrient trading among wastewater dischargers and non-point sources, or the development of new point- or non-point-source control technologies.

This plan specifically includes the following Ecological Research Program activities critical for watershed TMDLs and other cross-media, multi-stressor management problems:

- integrating hydrologic, landscape and air models to develop multi-pathway, multi-scale, multi-stressor TMDL models/framework,

- integrating with associations between risk management practices and loadings, and with correlations between pollutant concentration and biological condition, in order to forecast how risk management options will affect biological indices,
- characterizing scientific uncertainty and variability to reduce reliance on potentially overprotective and costly default MOS (Margin of Safety) assumptions, and
- identifying "sensitive" site-specific parameters which, were data available, would significantly reduce prediction uncertainty.

Thus, in addition to the computational and scientific aspects of modeling, significant advances in watershed biogeochemistry, atmospheric chemistry, landscape science, and ecological modeling, as generated by in-house and NCER-funded research and reflected in complementary APGs and APMs, will be incorporated into the prototype applications. STAR is funding specific research on the development of regional-scale stressor response models. These models incorporate multiple stressors, including embedded sediments, nutrients, changes in land uses, flow variability, etc., to predict changes in aquatic ecosystems.

To achieve the long-term goal, model research and development is being conducted in a variety of media. Watershed-based models are being developed for stressors with strong multimedia components of their exposures, such as nitrogen and mercury. An analytic element groundwater model is being developed that can provide base-flow estimates for streams. An improved approach for predicting atmospheric loadings to watersheds is being evaluated. These single-stressor, multimedia analyses are critical to such regulatory endpoints as whole-watershed TMDLs, watershed-scale pesticide management strategies, and mercury atmospheric source reduction, as well as constituting interim steps in the multi-pollutant strategy and regional assessments for development projections and restoration and management options.

Forecasting research within NHEERL focuses on developing methods and models to extrapolate individual-based responses to stressors up to population trends in a spatially explicit context. This research will help to predict population-level responses to stressors, including the spread and impact of invasive species on native species in terrestrial, estuarine, and freshwater systems. The principal contribution of this research will be methods and models to predict population responses to multiple interacting stressors within heterogeneous habitats. This research will also provide a methodology for predicting cumulative impacts of multiple stressors on interacting wildlife populations, models for conducting spatially explicit ecological risk assessments, and databases and models for conducting predictive community-level risk assessments that capture relationships between ecological and socioeconomic indicators.

In this LTG, the initial research focus is on

- characterizing ecosystem processes and properties to support forecasting and evaluation of alternative management practices (F1),
- forecasting human activities and natural processes that drive change in ecological systems (F2), and
- extrapolating relationships and linking model components across spatial and temporal scales (F3).

Building on the results of these first three subsidiary LTGs, the research focus shifts to

- linking or coupling models to forecast effects and apportion influences across media and stressors (F4),
- characterizing the sources and magnitude of uncertainties and variabilities for pairwise and more complex relationships (F5).

In the mature phases of the research, although activities in the lower-numbered sub-LTGs continue, research emphasis shifts to

- producing a decision support framework that includes models, modeling tools, and data access, manipulation, analysis and visualization (F6)
- establishing a capability for Regional, State, and watershed scientists and managers in the Mid-Atlantic region to anticipate threats to ecological resources using scientifically sound vulnerability and cumulative exposure assessments (F7)
- making protocols available that provide the scientific basis for predicting the ecological benefits of different management alternatives to Regional, State, and watershed organizations(F8)
- providing protocols to regional, State and watershed organizations that provide the basis for conducting predictive community-level risk assessments (F9)

The need to address more subtle environmental issues and to find more holistic solutions is increasing the importance of integrating conventionally disparate modeling domains, including multiple types of biota, multiple physical media, human behavior, and economic development. Creating and applying these integrated models raises numerous scientific, modeling, software, data, and organizational questions, e.g.,

- How should differences in temporal and spatial scales among models be resolved?
- When and how should mass and energy balance constraints be enforced?
- How can people from different disciplines and organizations most effectively focus on a common goal?

Some projects, such as the Hazardous Waste model development program, have demonstrated how some of these problems can be addressed, but serious challenges remain. To explore and

address those challenges, increasing emphasis will be placed on learning how to better develop interdisciplinary and integrated modeling systems through the selection and development of strategically chosen examples.

The degree to which potential harm to humans and ecosystems is in fact realized is often uncertain. Uncertainties result principally from lack of knowledge, and from uncertainties in data. Knowledge-based uncertainties hamper each step of a risk assessment or management alternatives evaluation. These arise from incomplete or inadequate characterization of physical, chemical, and biological processes, of the processes that generate stressors, of fate and transport processes (air, water, soil, biota), of exposure pathways to human and ecological receptors, and of their resulting effects and health implications. Uncertainties associated with data arise from inadequate measurement or data summary techniques, from an inappropriate characterization of heterogeneity at the site or ecosystem scale, and from the variability of geological, hydrological, and climatological conditions at locales across the geographic expanse of the United States. These uncertainties have led in some cases to the use of precautionary exposure assumptions, especially for direct pathways, that may over-predict risks. In a regulatory context this may result in unnecessarily increased economic costs. To improve the overall efficiency of regulatory programs, ORD is conducting research to improve risk assessment models and better characterize uncertainties.

A full multimedia modeling system that relies on multiple models and myriad data sets could be so complex as to be prohibitively difficult to set up and use. To address this problem, approaches for developing a multimedia modeling framework – a software infrastructure for modeling – are being created. The modeling framework will support developing, assembling, and applying cross-media models, and evaluating results and related information for environmental management and research needs. By providing tools for working with data and models and for automating common tasks, the framework will reduce the effort required to develop, apply, and evaluate multimedia modeling systems and to share models within the Agency and with other agencies, thus allowing people to better focus on the management issues they face.

NERL is developing the Multimedia, Multi-receptor, Multi-pathway Risk Analysis (3MRA), and the Multimedia Integrated Modeling System (MIMS). 3MRA is designed for site-scale modeling studies and is the more mature system. 3MRA activities are reflected in APGs within both the Hazardous Waste and the Ecological Research MYPs. Based on lessons learned from 3MRA and other modeling frameworks, MIMS is designed to provide a superset of 3MRA's functionality, including support for multiple scales and air-land-water feedbacks among landscape elements and ecosystems. MIMS activities are reflected in APGs of this Ecological Research Program. Both systems will include support for data analysis tools, quality assurance checks, access to local and remote databases, distributed and remote processing capabilities, and sensitivity and uncertainty analysis. (Uncertainly analysis has been identified as a critical need in

watershed/TMDL assessments and indeed in most ecological modeling intended for risk assessments and regulatory support applications.)

The frameworks are being applied to a variety of applications to develop and evaluate functionality across a wide range of questions, stressors, ecosystems, and scales encountered in assessments of ecosystem condition and evaluations of management and restoration options. 3MRA is being used to perform exposure and risk assessments of small watersheds and contaminated sites for RCRA and Superfund. In addition to supporting Hazardous Waste modeling, this work enhances framework development, model and database linkages, integration of endpoints of human and ecological health, and uncertainty analysis capabilities.

In the short-term, MIMS will be used for several applications that will test various capabilities for, or that will provide components of, a full multi-scale, multimedia model, such as a regional-scale mercury modeling system. A next-generation multimedia compartmental model with two-way feedbacks, EPA's Total Risk Integrated Methodology modeling system, and the Community Multiscale Air Quality Model will all use MIMS as their computational framework.

The ultimate outcome of these combined efforts is to provide a comprehensive set of modeling and supporting framework capabilities, accurately representing multimedia interactions among the physical and chemical environment, critical spatial features of the landscape (landscape ecology), and biological community and ecological processes.

4.1 Summary of non-EPA Forecasting Research Supportive of the Ecological Research Program

Development of multimedia modeling systems has been an active area of research since the early seventies, not only within EPA, but in other federal agencies and national labs, and in academic institutions. These efforts for the most part have been driven by specific problems or assessments, addressing the release, transport and fate of contaminants within and across environmental media. A variety of human health endpoints have been addressed, but most ecological endpoints were restricted to air, water, or sediment quality considered in isolation. More recently, agencies have been expanding their use of modeling programs to evaluation of the condition of ecosystems and the evaluation of abatement/restoration options. Development and preservation of wetlands and establishment of buffer zones along watercourses are important issues for many State and federal agencies, and modeling is playing an increasingly important role in the development and management of these resources.

ORD has identified a number of specific Federal Agencies with closely related and overlapping multimedia exposure and risk assessment modeling needs and research agendas. ORD research staff have met with counterparts from several of these organizations, identified areas of common

interests and needs, and developed a multi-agency Memorandum of Understanding (MOU) that was formally initiated in June of 2001. The original signatory agencies include (in addition to EPA/ORD):

- Nuclear Regulatory Commission, Office of Nuclear Regulatory Research
- Army Corps of Engineers, Engineer Research and Development Center
- Department of Energy, Office of Science and Technology
- Department of Interior, U.S. Geological Survey
- Department of Agriculture, Agricultural Research Service

The MOU establishes a framework for cooperation and coordination in research and development of multimedia environmental models. A central objective is to provide a mechanism for the cooperating agencies to pursue common technologies in multimedia environmental modeling with a shared scientific basis. Since the signing of the MOU, two workgroups have been formally established and two additional workgroups have been conceived. The two active workgroups are focusing on (1) software framework system design and (2) uncertainty analysis and parameter estimation. These workgroups are organizing common approaches to software development that will inform the design of future multimedia models and modeling frameworks. The framework workgroup is focusing on short- and long-term development of four major system components: integrating Geographical Information System (GIS) capabilities, database connectivity, software execution management, and data representation and interchange between models.

5.0 RESTORATION AND MANAGEMENT RESEARCH

5.1 Long-Term Goal

The long term goal of restoration and risk management research is that:

> ***Managers have scientifically defensible methods to protect and restore ecosystem condition.***

A subsidiary long-term goal for this effort provides a more definitive statement of the expected outcomes for the results of ORD's research. The subsidiary-long-term goal for restoration is:

> **Watershed managers have state-of-the-science field-evaluated tools, technical guidance, and decision-support systems for selecting, implementing, and evaluating cost-effective and environmentally-sound approaches to restore ecosystem services as part of watershed management.**

Initial research efforts focused ORD resources for restoration and risk management on the basic science issues to address processes important to the success of restoration implementation. These initial works have been coming to a close during the FY02 to FY04 periods. Today resources are being focused on the assessment of the effectiveness of restoration technologies and the benefits of restoration of degraded ecosystems, primarily in urban settings. It is anticipated that a similar subsidiary long-term goal will be developed for protection, or management research and will be implemented as resources become available.

Ecosystem restoration research addresses a major national need. Ecosystem services have been and continue to be lost in watersheds nationwide as a result of anthropogenic activities. For example, at least 40 percent of US waterways fail to meet standards for water quality. The challenge to ORD is to develop effective tools that can be used to identify, stop, and reverse the losses that have already occurred and to protect those watersheds that are threatened while integrating the contribution of local stakeholder groups. These groups can provide much-needed understanding for the impact of socio-economic factors for the valuation of the benefit of restoration efforts. In this manner, ORD's ecosystem restoration research is designed to develop strategies to better manage the land/water interface and adjacent upland areas to restore ecosystem services and to maintain chemical, physical, and biological quality in adjacent water bodies. It is anticipated that these strategies will be effective at achieving desirable ecosystem conditions and while being cost-effective for stakeholder and decision-makers. The program is being implemented through in-house research linked to collaborative efforts in other federal agencies and the academic community, and the STAR grant program.

(This program also provides the scientific underpinning for programmatic Goal 2.2.1: "By 2005, restore and protect watersheds so that 75 percent of waters support healthy aquatic communities as shown by comprehensive assessment of the nation's watersheds" and MYP Goal 2, LTG 3).

Essential ecosystem services are a result of naturally occurring ecosystem processes and include such necessities for human health as a reliable supply of clean water, production of oxygen, nutrient cycling, and soil genesis, as well as wildlife habitat and greenspace. Supplying ecosystem services by manufactured means on a global scale is prohibitively expensive and/or technically infeasible. Habitat destruction, invasive species, and non-point source pollutants such as excess nitrogen and eroded sediments adversely impact the provision of ecosystem services by contributing to the loss of ecosystems and/or their associated functions. Thus finding effective and efficient ways to protect and restore ecosystem services is necessary for human as well as ecological health. Healthy ecosystems are essential for healthy people.

As mentioned previously, ORD's Ecosystem Restoration research program has two major components. The first is to conduct fundamental research to better understand the processes and manipulations necessary to achieve restoration goals. By gaining insight into basic ecosystem processes, researchers may begin prescribing methods that alleviate stressor effects on the environment and allow ecosystems to provide vital ecosystem services at levels adequate for a growing global population. This component was the focus of a number of the projects initially funded through this program. The second component is to conduct applied field research to evaluate the effectiveness of restoration and management activities for achieving desired environmental conditions that support and maintain ecosystem services for society. The major emphasis of the program is currently with these type projects. These efforts will provide the necessary information and linkages for the assessment of the benefits of ecosystem restoration for both monetary and non-monetary valuation.

These evaluation projects are utilizing restoration efforts that are being conducted by stakeholders at the state and local level. For example a major effort of this program is being conducted where the county's Department of Natural Resources is carrying out the stream restoration work, while ORD is conducting the intensive measurement of the effectiveness of the restoration for achieving chemical, hydrologic, and biologic criteria as measurement of water quality. Although the need for a healthy riparian zone is well understood, many of the details of the benefits and effectiveness of specific actions to restore riparian zones as well as ecosystem services are poorly understood. Through these collaborative efforts, ORD is evaluating the effectiveness of riparian restoration techniques as tools to achieve goals such as water quality criteria or the restoration of specific ecosystem functions such as denitrification. The riparian zone is a critical component of any watershed. Without a healthy riparian zone, it would be difficult if not impossible to achieve water quality goals. Nationwide, large sums of money are being spent to repair and restore riparian areas. ORD is uniquely qualified and positioned for research efforts that will provide the tools necessary for the assessment of the benefit of these

restorations. These efforts are either currently being carried out or planned collaboratively with such organizations as Baltimore (Maryland) County's Department of Environmental Protection and Resource Management, the USDA's Forest Service, and the Canaan Valley Institute (West Virginia). This approach allows ORD to maximize the use of its resources by focusing them on an in-depth evaluation of the effectiveness of a suite of restoration activities rather than on a very limited attempt to actually carry out restoration work.

ORD has chosen to primarily focus its efforts on urban and near urban ecosystems. Many largely urban areas have begun committing resources to the improvement and restoration of near-stream properties that have to date been identified as severely degraded. By partnering with organizations conducting these restorations, ORD is fulfilling an important scientific niche by providing the expertise of evaluating the effectiveness and cost benefit of these restorations. This allows ORD's work to complement that of other federal agencies such as the USDA or the land management agencies whose focus is on other, largely rural areas. This role is explained in subsequent sections.

In addition to evaluating the effectiveness and benefits of restoration activities, ORD's approach allows for building experience in the development and utilization of adaptive management for restoration and maintenance of ecosystem health. At any given field site adaptive management will use a suite of tools available from all areas of this plan. Condition tools provide the means for establishing the status and trends associated with the condition of a system. Diagnostic tools provide the means for identifying the causes of ecosystem degradation and the basis for managing stressors that have resulted in the current condition. Forecasting tools then provide the means for predicting trends and outcomes of management actions or the lack thereof. Tools developed through the restoration efforts both require utilization of these other tools and provide a means for reducing the scientific uncertainty associated with these tools. The combined effort of these components provide an extensive suite of scientifically defensible tools needed for cost effective and predictable actions to restore and manage watershed ecosystems.

5.2 APGs and APMs

Progress toward the Restoration Subsidiary Long-Term Goal will be measured by achievement of a sequence of annual performance goals through 2008 aimed at developing the scientific knowledge, tools and guidance for restoring riparian zones, and prioritizing restoration activities to most efficiently accomplish watershed management goals (Figure 5).

The APGs for 2001 and 2002 have already been achieved. The first goal was to develop a comprehensive look at the range of restoration activities in the Mid-Atlantic Integrated Assessment region, building on progress in EMAP and ReVA in establishing a very thorough description of watershed conditions in the region. This provided a basis for better assessing

research needs and potential for restoration in specific watersheds by FY02. The FY 03 APG will complete the assessment by determining how well what is being done is actually working primarily in the MAIA region. Together, these three APGs provide information on the extent and effectiveness of riparian zone restoration activities in the MAIA region. The second FY03 APG will show the accomplishments of the STAR research to develop new approaches to prioritize, implement, and evaluate watershed rehabilitation efforts for a set of selected watersheds throughout the United States.

The FY 04 APGs represent major steps in the development of the basic scientific understanding of how riparian zones process nutrients, as well as providing tools for the determination of the risk of exceedance for specific stressors such as nutrients and sediments. This understanding will be used to provide tools to evaluate the potential benefits of riparian zones to control nutrient loadings to water bodies. The FY05 APG will turn this scientific understanding into a "how to" manual for restoring particular reaches. The FY06 APGs will add guidance and tools to prioritize the application of these restoration techniques to provide the most cost-effective restoration strategy for a watershed. In FY 07, these tool kits will be combined into an integrated guidance package for restoration of riparian buffers in humid eastern watersheds. The in-house research program is focused on the eastern United States, particularly the mid-Atlantic region. The STAR Water and Watersheds program has complemented the in-house program by supporting research on watershed rehabilitation applicable to any region of the United States. This work will be concluded in FY03. Additional STAR research will explore more general issues of prioritizing restoration within a watershed as well as among watersheds.

In FY08, the program begins to repeat the cycle for arid watersheds in the Western U.S. By 2008, the goal is to complete three pilot restoration projects as a proof of efficacy.

As has already been stated, the primary research efforts have been focused on building the fundamental knowledge related to processes in the restoration of ecosystems, and the evaluation of the effectiveness of restoration techniques to meet specific restoration endpoints such as water quality and biological integrity. Through a combination of intramural and extramural activities, the ORD program has focused on ecological processes and management actions within the riparian zone, understanding the set of watershed characteristics amenable to rehabilitation in the context of environmental and social factors, and what metrics or objective criteria should be used to answer questions such as: "Is it working?," "Is it clean enough?," "Are we doing more harm than good?."

Research to better quantify the benefits of restoration and develop cost/benefit ratios are areas of research that have only recently been initiated. Benefits research efforts will provide the tools necessary for prioritizing ecosystems for restoration and management of ecosystem services. Thus, as the restoration program moves ahead, the major changes will be to move from *process* understanding and *effectiveness* research to an increased emphasis on measuring the *benefits* of restoration. These benefits will likely be realized through measures of the ecological integrity of a resource, measures of societal value of the resource, as well as aesthetic value of the resource. Some of the benefits can be easily priced while others apply non-market alternative valuation measures, such as willingness to pay. Furthermore other benefits, *e.g.*, value to future generations and spiritual values, are difficult to impossible to monetize. Proposed research, both intramural and extramural, will explore new methods for valuing the ecological benefits of restoration.

5.3 Summary of non-EPA Ecosystem Restoration Research Supportive of Goal 8.1

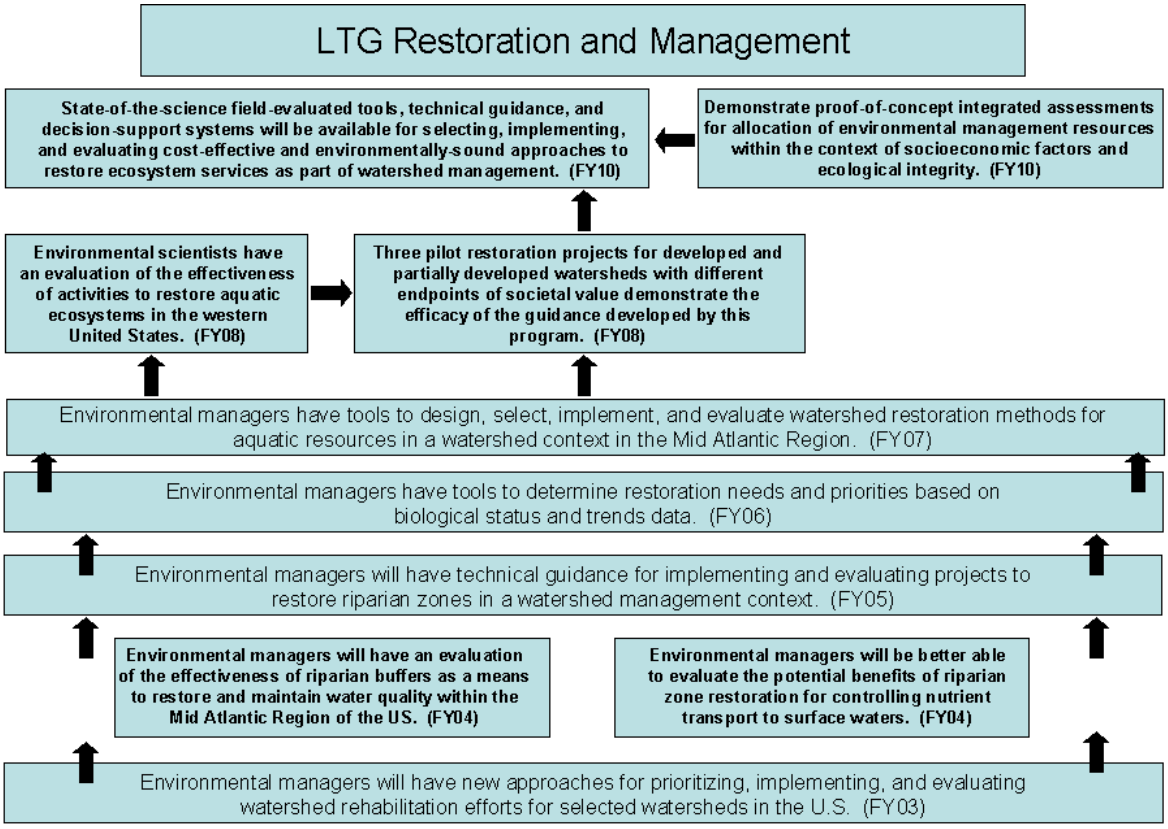


Figure 4 Flow Chart for Restoration APGs

A wide variety of organizations are engaged in ecosystem management and restoration activities aimed at achieving a wide variety of endpoints. These organizations include the federal resource management organizations, such as the Forest Service, the USDA which has the goal of establishing two million miles of buffers in agricultural areas, state and local watershed management districts, and private organizations such as The Nature Conservancy and Ducks Unlimited. Other agencies, such as the USEPA's Office of Water are actively engaged in encouraging and facilitating watershed management and restoration activities by non-federal organizations. However, only a few of these organizations have programs in place to systematically assess the benefits of specific actions or to conduct research to strengthen the scientific basis underlying ecosystem management and restoration.

The USDA through its Natural Resource Conservation Service (NRCS) and the Agricultural Research Service (ARS) conducts research on the benefits to water quality of buffer zones along streams in agricultural areas. ORD is actively collaborating with the United States Geological Survey (USGS) on a number of ecosystem restoration projects. In addition, USGS data on water quality, which is collected as part of the NAWQA program, is one of the primary sources of information for efforts to restore water quality. The US Army Corps of Engineers Waterways Experiment Station has an active program of ecosystem restoration research to support the Corps' responsibilities for maintaining wetlands and navigable waterways. The US Forest Service as an active research program on riparian zone management to support its responsibilities to manage the nations forests in a way that preserves ecological values in adjacent waterways as well as in the forest lands themselves. Private and university-based research organizations such as the Stroud Water Research Institute near Philadelphia have long histories of ecosystem management and restoration research, often supported by federal agencies such as the National Science Foundation. ORD is actively engaged in trying to coordinate its research with these organizations where it is appropriate to do so. In addition, ORD is focusing its research on suburban and other areas in close proximity to developing urban areas which typically fall outside the purview of other federal agencies such as USDA.

6.0 INTEGRATED APPLICATION AND DEMONSTRATION PROJECTS

One programmatic goal for the program is:

> ***Reliable and robust protocols are readily available to managers working in watersheds, States, regions, and tribes to conduct scientifically defensible assessments of current and future condition, causes of impairments and management alternatives.***

Broad-based agreement on the ways we assess the impacts of human activities on ecological resources will let environmental managers and the public more effectively identify where the most urgent environmental problems occur, and more efficiently seek creative solutions that will improve environmental condition. Although substantial progress has been made in articulating the principles of unbiased sampling, identifying indicators, and assessing ecological conditions and risks, further progress is needed to ensure that survey designs fit decision-making needs, that indicators are selected for relevance to decisions rather than expediency, and that assessment results are comparable. The ultimate outcome is that environmental data and assessment results effectively inform the complex decisions facing environmental managers throughout this country, from those working at the watershed level, to state and regional managers, to those working at the national scale. Although research conducted under this Program generally contributes to achieving this goal, the Program also conducts place-based concerted implementations intended as demonstration and pilot programs to facilitate transfer of the research findings into regular practice.

Managers currently use ecological assessment results to address four general categories of questions:

1. What is the condition of our resources?
2. What is causing observed degradation?
3. How can we better anticipate future threats to valued resources?
4. How can we best fix the problem?

   What are the effects of current policies and management programs? (Is what we are doing now producing the intended ecological outcomes? If not, what more should be done?)

The place-based application program is structured around these four general purposes. Under each purpose, we intend to develop, demonstrate and test methods in one or two regions, solidify the lessons learned by producing guidance, and ensure that the methods and guidance are available in relevant forms to the scientists and managers who be using them for adaptive management. Place-based applications integrate results from all parts of the Ecological Research

Program (i.e., monitoring, diagnostic and forecasting research, and management and restoration research). In addition, they draw from applied research on stressor-response and diagnostic relationships being conducted under the other MYPs (particularly Water Quality, Safe Ecosystems, and Hazardous Waste). Finally, this research cannot be successful without the involvement of the regional, state and watershed scientists and managers. Assessors are increasingly realizing that three groups are vital for developing new scientific methods and getting managers to use them:

- Researchers and scientists who want to develop new approaches and work towards having them be implemented/institutionalized (ORD scientists fill this role).
- Managers who want better data, methods, and approaches to help resolve issues, problems, etc. (Regional, Tribal, State and local managers with environmental responsibilities fill this role)
- Facilitators and communicators who operate between the first two groups to help translate the science for the managers and translate the managers' needs for the researcher. (NGOs, some academics, and trained facilitators fill this role).

The emphasis on producing and disseminating guidance shown below reflects the need to document and communicate the lessons learned from developing and applying these research results. In this way, assessors and managers throughout nation can build on the experiences of ORD and its partners when addressing similar questions in additional localities.

Figure 6 shows a series of synthesis documents and technology transfer activities that will improve ability to address the above five categories of questions, and accomplish the long term goal of the Ecological Research Program. Each series begins with work in the Mid-Atlantic to develop, demonstrate and test methods. This joint ORD/Region 3 Program (the Mid-Atlantic Integrated Assessment, or MAIA) is a partnership of the federal, state, and local agencies, many NGOs, academia, and private sector components with responsibilities for environmental issues in the Mid-Atlantic area. Working cooperatively with the MAIA Program, research conducted in ORD laboratories and centers will be combined with results from the grants program to produce guidance on each type of assessment. The methods and lessons learned in the Mid-Atlantic will then be extended by conducting research in a complementary region, most probably in the western U.S. Each series ends by supplementing guidance materials based on the additional experiences. The time frames for each series activities overlap, which will allow for cross-fertilization and leveraging across the different assessment purposes. In the cases of assessments of cause, predictions and management alternatives, several activities planned for the second region and subsequent guidance will occur post 2008, and so are not specifically tabulated.

Many of the ecosystem analysis and management activities in the Federal Government are coordinated under the Committee on the Environment and Natural Resources. For example, this group reviewed protocols for ecological risk assessment across activities such as assessment of

risks of introduced species, and Natural Resource Damage Assessments (Committee on Environment and Natural Resources 1999) and recently coordinated a paper on Ecological Forecasting (Committee on Environment and Natural Resources 2001). The U.S. Geological Survey is particularly active in assessments of condition for water quality (U.S. Geological Survey 1999). Several states are also active in developing protocols for assessing condition and the causes of observed impairments. Finally, program offices within EPA also develop protocols for assessments for specific purposes. ORD support for these activities is reflected under the relevant MYPs (e.g., Water Quality, Safe Communities and Ecosystems, and Hazardous Waste).

7.0 FUTURE DIRECTIONS WITH INCREASING FUNDS

7.1 Ecological Indicators

ORD's ecological indicators program has focused on the development of the next generation of indicators that (1) integrate between or among resource types, (2) incorporate multiple levels of biological organization (gene, organism, population, community, landscape), and (3) address multiple spatial scales (local, watershed, regional, national, global).

While these integrative indicators are important in assessing ecosystem health, they may not be adequate to measure the effectiveness of national programs, such as the Clean Water Act. Additional funds would be applied to the develop of a suite of indicators designed for this. To assess whether our nation's waters are improving, one approach that could be implemented is suggested in the SAB report: *A Framework for Assessing and Reporting on Ecological Condition.* A hierarchical approach is outlined with the goals and objectives of the program defining the essential ecological attributes of interest (landscape condition, chemical and physical characteristics, ecological processes, etc.). This directs the selection of ecological endpoints (indicators), and thus defines the monitoring program. A suite of indicators from simple chemical or physical measurements through complex integrated indices could be made available so that the practitioner would have indicators available at the appropriate level of complexity for the question asked. A significant challenge for the program is to develop scientifically valid indicators that integrate measures of ecological condition into easily communicated measures of the effectiveness of EPA's actions. This accountability is especially important as we are increasingly being questioned on the benefits of environmental programs.

7.2 Invasive Species

While zebra mussels and lampreys are the best known of the invaders in the Great Lakes, more than 140 aquatic nuisance species have invaded the Great Lakes since the 1800s. Alarmingly, the rate of introduction has increased, with many of the invaders introduced in the last few decades. These invasions are likely to continue as about 30 additional foreign species have been identified as potential invaders to the Great Lakes. The expanded research on invasive species will focus on the threat of NEW INVADERS to the ecological integrity of the Great Lakes. The goal will be to develop integrated methods of detecting and predicting the spread of new invasive species introduced into the Great Lakes. Successful rapid response requires both early detection of new invaders and a prediction of their spread based on the patterns of invasion vectors (e.g., shipping) and the inherent vulnerability of different ecosystems to invasion. A workshop will be held that

will help better refine which potential invaders and invasion models to focus the subsequent research on.

7.3 Benefits of Ecological Restoration

ORD's restoration research program has been supported through a combination of intramural and extramural activities. The ORD program has focused on ecological processes, management actions, and measuring effectiveness within the riparian zone, understanding the set of watershed characteristics that are amenable to rehabilitation in the context of environmental and social factors, and what metrics or objective criteria should be used to answer the questions "Is it working?" "Is it clean enough?" "Are we doing more harm than good?"

As additional funds are added to the restoration program, the major changes will be to augment the research on measuring the *benefits* of restoration.. Benefits associated with restoration may be ecosystem services, such as bee pollination or sediment trapping in wetlands. Other benefits may be aesthetic and others may be for ecological integrity of the resource. Some of the benefits can be easily priced while others apply non-market alternative valuation measures, such as willingness to pay. The proposed research will explore new methods for valuing the ecological benefits of restoration.

Additionally, a growing program would broaden the research on understanding the effectiveness of restoration in different regions of the country. This would build on the effort currently underway in the Mid-Atlantic and Great Basin regions.

8.0 REFERENCES:

CENR 1997. Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework. March 1997. National Science and Technology Council, Committee on Environmental and Natural Resources, Environmental Monitoring Team. Washington, DC.

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Appendix 1
Sub-Long-Term Goals, Annual Performance Goals and Annual Performance Measures for Each Long Term Goal

Table 1 – Long-Term Goal: Condition

LTG 1 -The states and tribes use a common monitoring design and appropriate ecological indicators to determine the status and trends of ecological resources

Sub LTG C1: A monitoring framework is available for streams and rivers in the Western U.S. that can be used from the local to the national level for statistical assessments of condition and change				2008
APG 47 - Baseline ecological condition of Western streams determined		2005	NHEERL	External
	Partners sample streams in 12 Western states	2002	NHEERL	
	Upper Missouri River sampled	2002	NHEERL	
	Partners sample streams in 12 Western states	2003	NHEERL	
	Upper Missouri River sampled	2003	NHEERL	
APM 53	Draft report on ecological condition of Western streams	2004	NHEERL	
APM 54	Report on the assessment of large reservoirs of the Upper Missouri River	2004	NHEERL	
	Report on ecological condition of Western Streams produced	2005	NHEERL	External
APG - Probabilistic design framework developed that allows for aggregation of state monitoring to establish aquatic ecosystem condition in the West		2006	ORD	Internal
	Correlations between stream condition and landscape indicators tested (ESD: 6821)	2005	NERL	
	Landscape metric-stream condition relationships tested in Western US (ESD:6821)	2005	NERL	
APG - Condition of the Western aquatic ecosystems established		2008	ORD	Internet
	Report on excess sediments index for flowing waters	2005	NHEERL	
	Report on development of habitat quality index for flowing waters	2006	NHEERL	
	Compile Western Pilot Data Set for analysis	2006	NHEERL	
	Report on definitions and approaches for establishing reference conditions	2006	NHEERL	
	Draft report on ecological condition of western aquatic ecosystems produced	2006	NHEERL	

	Report on condition of western aquatic ecosystems published	2007	NHEERL	
	Guidance on consistent development of biological indices	2007	NHEERL	
	Landscape metrics used to estimate pesticide and toxics loadings to Western US streams (ESD: 5448)	2007	NERL	
	Final report on frame quality for stream and river monitoring (Synthesis document)	2008	NHEERL	
Sub-LTG C2: A national monitoring framework is available for estuaries that can be used from the local to the national level for statistical assessments of the condition and change				2008
APG 31 - Provide the public with a reliable picture of the condition of the Nation' s estuaries		2006	NHEERL	Internal
	Report on the comparison of the conditions determined from probabilistic surveys of the National Estuarine Program estuaries and overall US estuarine condition	2005	NHEERL	
	Report on the condition of the estuarine resources of Veracruz, Mexico	2005	NHEERL	
	Report on contaminant bioaccumulation in fish tissues in the estuaries of the US	2005	NHEERL	
	Report on the condition of estuarine resources in California	2005	NHEERL	
	Report on the condition of 3 EPA Regions (1,2,4)	2005	NHEERL	
	Report on the probabilistic survey design and response design necessary to assess the condition of estuaries throughout the Gulf of Mexico	2006	NHEERL	
	Report on the condition of 2 EPA Regions (3, 6)	2006	NHEERL	
	Report on the condition of estuarine resources in Oregon and Washington	2006	NHEERL	
	Report on the indicators necessary to assess estuarine condition	2006	NHEERL	
APG 102 - Report on condition of Nation's estuaries		2006	NHEERL	Internal
	Final Report on condition of Nation's estuaries (Synthesis Document)	2006	NHEERL	
APG 48 - Condition of near-shore coastal ecosystems determined for Western US		2007	NHEERL	Internal
	Partners sample Western near-shore coastal Ecosystems	2003	NHEERL	

APM 55	Draft report on condition of near-shore coastal ecosystems in the Western US	2004	NHEERL	
	Report on the condition of estuarine resources in south-central Alaska	2005	NHEERL	
	Report on the condition of estuarine resources in Hawaii	2005	NHEERL	
	Report on the condition of near-shore coastal ecosystems published in the Western US	2005	NHEERL	
	Report on a survey of the condition of off-shore coastal waters of the Western US	2006	NHEERL	
	Report on the condition of coastal resources (estuarine and intertidal ecosystems) for the Western US	2006	NHEERL	
	Provide overview and summary document of research on near-coastal ecosystems in the Western US (Synthesis Document)	2007	NHEERL	
APG - Determine the distribution of existing species and the current extent of invasion in marine/estuarine systems, the Great Lakes, and key freshwater streams		2010	NHEERL	Internal
	Generate an inventory of the current distribution of native and invasive species in marine/estuarine system, the Great Lakes and key freshwater systems using existing monitoring information	2006	NHEERL	
	Report on new introductions and changes in the distribution of existing invasive species in marine/estuarine systems, the Great Lakes, and key freshwater streams	2010	NHEERL	
Sub-LTG C3: A National monitoring framework is available for flowing waters that can be used from the local to the national level for statistical assessments of their condition and change				2009
APG - Provide a framework for conditions on flowing waters		2009	NHEERL	Internal
	Report on Design options for monitoring flowing waters	2008	NHEERL	
	Report on survey designs for national survey of flowing waters	2009	NHEERL	
Sub-LTG C4: A National monitoring framework is available for freshwater wetlands that can be used from the local to the national level for statistical assessments of their condition and change				2009
APG - Provide a framework for assessment of freshwater wetlands		2009	NHEERL	Internal
	Report on assessment of wetland condition in the Janiata Watershed, PA	2005	NHEERL	

	Report on wetland condition in the Nanticoke watershed (Delaware and Maryland)	2005	NHEERL	
	Report on core indicators for wetland monitoring and assessment	2007	NHEERL	
	Report on final survey design for monitoring freshwater wetlands	2009	NHEERL	
Sub-LTG C5: Consistent land use/land cover databases are available for the U.S. as well as techniques to efficiently measure changes and understand the significance of changes over time				2007
APG 49 - Provide Federal, State and local water resource managers with reliable, nationally-consistent indicators of water quality derived from landscape information for determining the ecological condition of surface waters		2004	NERL	Internal
WQ MYP APM 318	*Landscape atlas for pesticides, nutrients and sediments for streams in Mid-Atlantic coastal plain - Water Quality MYP APG 9, 2004 (ESD: 5448)*	*2004*	*NERL*	
APM 277	Accuracy assessment of the 1992 multi-resolution land characteristics (MRLC) national land cover data (ESD:8878)	2004	NERL	
APM 258	Sampling design to assess National change in land cover tested (ESD:5447)	2004	NERL	
	Landscape approach for assessing pesticide and toxics impaired streams in Mid-Atlantic tested (ESD:5448)	2004	NERL	
APM 278	Prototype methods for monitoring regional land cover change (ESD: 5445)	2004	NERL	
APG - National assessment of consequences of landscape change		2007	NERL	Internal
	Landscape indicators developed for US (ESD:5447)	2005	NERL	
	National landscape atlas produced from early 1990s MRLC data (ESD:5447)	2006	NERL	
WQ MYP	*Land cover/Land use digital database for watersheds in southwest U.S. publically available via website (ESD) - Water Quality MYP APG 2008*	*2006*	*NERL*	
	Land cover conversions estimated for selected ecoregions in the US (ESD: 5447)	2006	NERL	
WQ MYP	*Landscape atlas for pesticides and nutrients in Midwest streams (ESD: 5448) - Water Quality MYP APG 2008*	*2006*	*NERL*	
WQ MYP	*Landscape atlas for pesticides and nutrients in California streams (ESD:5448) - Water Quality MYP APG 2008*	*2007*	*NERL*	

	Assessment of the consequences of National landscape change from 1970s to 2000s published (ESD: 5447 Synthesis Document)	2007	NERL	
Sub-LTG C6: Methods to effectively monitor trends in environmental condition with known confidence are available to EPA, the States, and Tribes				2006
APG - Use of probability sampling for detecting trends in ecosystem condition established		2006	NHEERL	Internal
APM 103	Report on the application of surveys to detect trends while still describing ecological condition of estuaries in Virginian, Carolinian, Louisianian, and West Indian Provinces	2003	NHEERL	
	Complete first national trends report on conditions of estuarine ecosystems	2005	NHEERL	
	Report on trends of acidification status in sensitive waters	2006	NHEERL	
	Report on model to detect trends in ecosystem conditions	2006	NHEERL	
APG 50 - Improved/new ecological condition indicators developed		2006	ORD	Internal
	State-of-science report on ecological indicators published	2002	NCER	
	New ecological indicators developed for measuring environmental condition	2002	NCER	
	New molecular diagnostic indicators produced	2002	NERL	
	Report on new Index of Habitat Integrity for evaluating the health of forested head-water ecosystems.	2002	NCER	
	Report on new ecosystem indicators for evaluating the health of urbanizing Midwestern watersheds.	2002	NCER	
	Report on new ecological indicators for evaluating the health of large flood plain landscapes.	2002	NCER	
	Report on a new indicator for evaluating the health of coral reefs	2002	NCER	
APM 255	Prototype indicators of condition for deep river fish assemblages developed (EERD: 8734)	2004	NERL	
APM 37	Report on the development and evaluation of the next generation of genetic and environmental indicators.	2004	NCER	
APM 38	Report on the development and evaluation of an amphibian index for assessing stream health	2004	NCER	

APM 40	Report on effects of forest and landscape fragmentation as an indicator of net ecosystem productivity	2004	NCER	
	Synthesis report on improved new ecological indicators	2006	NCER	
Sub-LTG C7: Methods are available to integrate monitoring approaches and data across multiple scales, ranging from remotely sensed data over large regions to measures of chemistry and biology at individual sites				2012
APG 51 - Scaling protocols for linking index sites, geographic surveys, and landscapes in a multi-tier design established		2004	NCER	Internal
	New approaches to regional scaling and assessment published	2002	NCER	
	Synthesis publication evaluating the State-of-the-Science on regional scaling approaches	2003	NCER	
	Approaches published on regional scaling and assessment	2003	NCER	
APM 39	Reports on new regional scale approaches for monitoring and ecosystem assessment	2004	NCER	
APG - Methods for assessing ecological condition are demonstrated in the Mid Atlantic region		2005	ORD	Internal
	Integrated assessment protocols developed for Mid Atlantic Streams Estuaries, and landscapes	2001	NHEERL NERL	
	Published conceptual models for the Mid-Atlantic	2002	NCEA	
APM 110	Report on methods for assessing the relative severity of ecological effects across different stressors for Mid-Atlantic streams.	2004	NCEA	
	Report(s) on development and application of nested ecological indicators for use in an integrated assessment in the Mid-Atlantic	2005	NCER	
	Report on the development and application of a watershed similarity index to facilitate extrapolation of results across a Region	2005	NCER	
APG 52 - Monitoring protocols established for Regional/State aquatic ecosystem condition		2006	ORD	Internal
	MAIA streams report published	2002	NHEERL	
	Ecosystem classification scheme for Western streams developed	2002	NHEERL	
	Upper Missouri River monitoring protocols tested	2002	NHEERL	

WQ MYP	*Report comparing differences among invertebrate data collected using EMAP, NAWQA and OEPA methods (EERD) - Water Quality MYP*	*2003*	*NERL*	
APM 41	Emerging cross regional coastal issues arising from EaGle's program collaborative efforts	2004	NCER	
APM 252	Report produced on associations among invertebrates and habitat indicators for large rivers in the Midwest (EERD: 8734)	2004	NERL	
APM 253	Statistical and analytical guidance developed (including case studies) to help states choose scientifically sound methods for setting biocriteria (EERD: 8734)	2004	NERL	
	Report on the comparison of random site selection and modified random site selection for assessment of wadeable streams in Wisconsin (EERD: 6600)	2005	NERL	
	Report(s)on new regional coastal monitoring and assessment approaches	2006	NCER	
	Report(s) on the development of new watershed classification schemes that will facilitate application of biocriteria.	2006	NCER	
APG- Develop ecological condition indicators		2009	NCER	Internal
	At least one report on new indicators (plant, fish and invertebrate of wetland ecosystem integrity developed for use in assessing wetland health in the West	2005	NCER	
	Report on the extent, distribution and vegetation types of Great Lakes coastal wetlands	2005	NCER	
	Report on a suite of diatom-based indicators to measure condition in terms of conductance, nutrient load, and water transparency in the Great Lakes coastal zone	2005	NCER	
	Report describing relationships between habitat and landscape disturbances (e.g., urban and agricultural development) and bird/amphibian assemblages in the Great Lakes coastal zone	2005	NCER	
	At least 1 report on optical indicator(s) of habitat suitability for submerged aquatic vegetation	2005	NCER	
	At least 1 report on the development of indicators of nutrient status, estuarine water quality, and coastal wetland productivity base on plant pigments	2005	NCER	

	Report on the evaluation of sea grasses as indicators of water quality and habitat condition/change	2005	NCER	
	Report on nutrient indicators for coastal water quality assessment (bays and estuaries) developed from monitoring data collected by ferries, ships (A ships of opportunity)	2005	NCER	
	At least 1 report on molecular indicators of dissolved oxygen stress in blue crabs and shrimp, biomarkers of reproductive impairment in fish, stressor response relationships of the benthic macrofauna; and microbial biofilms as indicators of estuarine ecosystem integrity within selected Gulf of Mexico estuaries	2005	NCER	
	Report on indicators of stress in Pacific tidal wetlands for specific plants, fish, and invertebrates	2005	NCER	
	Report on indicators of ecosystem condition Pacific tidal wetlands	2005	NCER	
	Report on case studies and practical techniques for applying indicators of stress and indicators of ecosystem condition for California wetlands	2005	NCER	
	Report on population models of biomarker exposure in fish, crabs, and shrimp	2006	NCER	
	Report on Neural Network models of indicators of estuarine health	2006	NCER	
	Report on GIS model of estuarine indicators for targeted Gulf of Mexico ecosystems	2006	NCER	
	Report on vegetation indicators of human disturbance in Great Lakes coastal wetlands	2006	NCER	
	Report on the development of multi-variate indicators of ecological condition based on bird and amphibian assemblages in the Great Lakes coastal zone	2006	NCER	
	Report on the utility and predictive capacity of selected fish, invertebrate, and habitat indicators proposed by the State of the Lakes Ecosystem Conferences (SOLEC) to document the condition of the Great Lakes coastal margins	2006	NCER	
	At least 1 report on molecular indicators of dissolved oxygen (DO) stress in blue crabs and shrimp	2006	NCER	
	Report on microbial biofilms tested and evaluated as indicators of ecosystem integrity	2006	NCER	

	Report on the use of indicators to distinguish nutrient from climate-driven changes in water quality and habitat condition	2006	NCER	
	At least 1 report on applying indicators across estuarine and coastal systems having different hydrologic regimes, nutrient and toxic stresses	2006	NCER	
	Report on the applicability of indicators to regional (Atlantic-Gulf-Pacific-Great Lakes) comparative assessments of water quality and ecological condition	2006	NCER	
	One or more reports on the development of indicators of nutrient status and coastal wetland productivity based on plant pigments	2006	NCER	
	Report on genomic methods for assessing condition of water quality	2009	NCER	
APG-Develop an approach for establishing linkages between terrestrial/aquatic ecological condition		2012	NHEERL	Internal
	Report on candidate indicator species to assess linkages between terrestrial/aquatic ecological conditions	2008	NHEERL	
	Report on design framework to assess linkages	2010	NHEERL	
	Report on approach to assess linkages	2012	NHEERL	
APG - Develop approaches for integrating 305(b)/303(d)		2012	NHEERL	Internal
	Report on preliminary approaches demonstrating integration of 305b/303d	2005	NHEERL	
	Report on options for improving 303d listing	2008	NHEERL	
	Report on models that link landscape indicators to aquatic endpoints	2008	NCER	
	Develop an approach for developing headwater criteria using probability data	2009	NHEERL	
	Report on regional demonstration of 305b/303d integration	2012	NHEERL	
Sub-LTG C8: A monitoring framework is available for rivers and the Great Lakes in the Central U.S. that can be used from the local to the national level for statistical assessments of the condition and change				2015
APG 57 - Initiate monitoring program for the Missouri and upper Mississippi Rivers of the Central Basin		2003	NHEERL	Internal
APM 234	Establish States and Federal partnership	2003	NHEERL	

APM 233	Initial sample design framework and indicators for Missouri and upper Mississippi Rivers of the Great Basin	2003	NHEERL	
APG - Methods for establishing condition of Great Rivers of Central Basin developed		2009	ORD	Internal
	Draft report on ecological condition of the Upper Missouri River produced	2005	NHEERL	
	Report on new indicators developed for use in assessing the ecological integrity of the Great Rivers of the Central Basin	2008	NCER	
	Report on the integrated indicators of ecological and economic sustainability	2008	NCER	
	Methods for applying EMAP indicators of condition to the management of specific environmental problems in the Central Basin	2008	NCEA	
	Report on models that link landscape attributes to hydrological, ecological or socioeconomic endpoints	2008	NCER	
APG -Develop monitoring framework to enable integrated Great Lakes assessment across coastal, nearshore, and offshore ecosystems		2012	NHEERL	Internal
	Report on evaluation of nearshore designs and indicators across the Great Lakes	2004	NHEERL	
	Report on embayment designs and indicators across Great Lakes	2005	NHEERL	
	Provide initial assessment report on factors affecting nearshore conditions in the Great Lakes	2006	NHEERL	
	Report on the integration of at least one improved indicator into monitoring designs for coastal wetlands across the Great Lakes	2007	NHEERL	
	Report on provisional assessment of embayments and factors affecting condition in the Great Lakes	2008	NHEERL	
	Report on provisional assessment of coastal wetlands and factors affecting condition across the Great Lakes	2009	NHEERL	
	Provide integrated monitoring design for Great Lakes waters from coastal ecosystems to offshore waters	2010	NHEERL	
	Report on assessment of Great Lakes aquatic systems and likely stressors affecting condition	2012	NHEERL	
APG - Probabilistic monitoring framework for an integrated Central US basin assessment developed		2015	ORD	Internal

	Develop probability monitoring framework for Great Lakes	2004	NHEERL	
	Partners initiate sampling Missouri/Upper Mississippi	2004	NHEERL	
	Pesticide- and toxics-impaired Midwestern streams estimated from landscape metrics (ESD:5448)	2005	NERL	
	Landscape metric-river condition relationships tested for Upper Missouri and Mississippi River basins (ESD: 6821)	2005	NERL	
	Report on core indicators selected for assessing condition of the Missouri and upper Mississippi Rivers	2005	NHEERL	
	Transfer assessment technology for Missouri/Upper Mississippi to partners	2006	NHEERL	
	Investigate effects of land use change on aquatic ecosystems in the western US and the Mississippi River Basin using linked water resource and land use change models (ESD: 5442)	2007	NERL	
	Report on assessment of condition of the upper Missouri River	2007	NHEERL	
	Report on central basin great river design	2007	NHEERL	
	Provide field operations manual for great rivers	2007	NHEERL	
	Report on initial assessment of the condition of the Missouri and upper Mississippi Rivers	2007	NHEERL	
	Report preliminary results on use of probability monitoring framework for Great Lakes sampling	2008	NHEERL	
	Provide prototypic protocols and sample designs for assessing ecological conditions in Great Rivers	2008	NHEERL	
	Begin sampling Great Lakes with partners	2009	NHEERL	
	Report on assessment of the Missouri and upper Mississippi Rivers and likely stressors influencing condition	2009	NHEERL	
	Report on comprehensive sample design framework for Great Rivers	2010	NHEERL	
	Report on core indicators for assessing condition of Great Rivers	2010	NHEERL	
	Report on initial assessment of condition of Great Rivers	2011	NHEERL	
	Report on conditions of Great Lakes	2013	NHEERL	
	Report on final design for all Great Lakes	2014	NHEERL	

	Report on assessment of the condition of the Great Rivers of the Mississippi Basin and likely stressors influencing condition (Synthesis Document)	2015	NHEERL	
Sub-LTG C9: The states and tribes use a common monitoring design and appropriate ecological indicators to allow a scientifically-valid determination of the status and trends of their aquatic resources, to improve the cost-effectiveness of their environmental programs and policies, and to allow their findings to be aggregated into regulatory decisions				2007
APG 53 - National probabilistic stream and estuarine monitoring frameworks developed		2007	ORD	Internal
APM 42	Report on the development and evaluation of new ecosystem classification schemes and associated reference conditions for developing cost-effective monitoring protocols	2004	NCER	
	Report(s) on new approaches for statistical survey design and analysis for aquatic resources	2005	NCER	
	Report(s) on reference conditions and resource/ecosystem classification schemes for adoption by regional and state water quality managers.	2006	NCER	
	Report(s) on new approaches for statistical survey design and analysis for aquatic resources	2006	NCER	
	Landscape stressors to streams in US estimated (ESD: 5447)	2007	NERL	
	At least 25 states have adopted and are using an EMAP-like design for monitoring stream and estuarine condition in their state	2007	NHEERL	
Sub-LTG C10: Development and application of a methodology to utilize existing survey information to diagnose the ecological condition of all estuarine resources				2012
APG - Development of approach to permit diagnosis of the ecological condition of all estuarine resources		2005	ORD	Internal
	Report on the approach to diagnose the ecological condition of unsampled estuarine resources based on landscape information and probabilistic surveys	2005	NHEERL	
APG - Assess the condition of all US estuarine ecosystems using pilot surveys and models		2012	NHEERL	
	Report on the application of the landscape modeling approach at a local scale (single estuarine system)	2006	NHEERL	
	Report on the application of the landscape modeling approach at the regional scale (Gulf of Mexico)	2007	NHEERL	

	Report on the application of landscape modeling approach at the regional scale (Southeastern US)	2008	NHEERL	
	Report on the application of landscape modeling approach at the regional scale (Northeastern US)	2008	NHEERL	
	Report on the application of the landscape modeling approach at the regional scale (Western US)	2009	NHEERL	
	Report on the national application of the landscape modeling approach	2010	NHEERL	
	Report on the use of the landscape modeling approach to characterize the 303d listing of US estuarine resources	2012	NHEERL	
Sub-LTG C11: Implementation of a national monitoring framework for coastal ecosystems that can be used at the state, regional, and national levels for statistical assessment of ecological conditions and change				2012
APG - Report on the condition of all coastal resources in the US		2012	NHEERL	Internal
	Report on the survey design and response design necessary to assess the condition of the coastal wetlands of the US	2005	NHEERL	
	Report on the condition of the estuarine and offshore coastal resources of the Northeastern US	2007	NHEERL	
	Report on the condition of the estuarine and offshore coastal resources of the Southeastern US	2007	NHEERL	
	Report on the condition of the estuarine and offshore coastal resources of the Gulf of Mexico	2007	NHEERL	
	Report on the condition of the coastal wetlands and intertidal ecosystems in the Western US	2008	NHEERL	
	Report on the condition of the estuarine and offshore coastal resources of the US	2008	NHEERL	
	Provide the Third National Coastal Condition Report	2008	NHEERL	
	Report on the condition of the coastal wetlands of the Northeast	2009	NHEERL	
	Report on the condition of the coastal wetlands of the Southeast US and Gulf of Mexico	2009	NHEERL	
	Report on the condition of the coastal wetlands of the US	2010	NHEERL	
	Provide the National Coastal Condition Report for US estuaries, wetlands, and offshore ecosystems (Synthesis Document)	2012	NHEERL	

Note: NERL APMs include information to identify specific organizational branches responsible for the research effort and research task numbers.

Table 2 – Long-Term Goal: Diagnosis				
LTG 2 - Managers and researchers understand links between human activities, natural dynamics, ecological stressors and ecosystem condition				
Sub LTG D1: Environmental managers are able to characterize ecosystem properties and processes in a manner that supports diagnosis of current condition				2008
APG 54 Environmental managers are able to characterize and quantify aquatic resources for streams in the mid-Atlantic region		2004	ORD	Internal
	Measurements and models of invertebrate and fish populations are available for selected watersheds and stream reaches of the mid-Atlantic Highlands	2004		
APG 55 Environmental managers are able to implement new, more efficient methods for stressor identification and characterization		2005	ORD	Internal
	Hyperspectral methods are developed to detect rangeland stressors in western watersheds (ESD:5626)	2003	NERL	
APM 201	Report on application of EDC exposure detection methods to risk management strategies for aquatic ecosystems (EERD: 6498)	2004	NERL	
APM 254	Empirical model developed linking spectral measurements with nutrient and sediment concentrations for deriving continuous coverage of the Ohio River (EERD: 6600)	2004	NERL	
APM 270	Development of DNA microarrays for the fathead minnow, *Pimephales promelas*, fixation of genomic sequences on glass matrix (DNA chip) for diagnosis of exposure to specific aquatic stressors (EERD: 6498)	2004	NERL	
APM 271	Report on the presence of estrogenic and androgenic substances in effluents from concentrated animal feeding operations (EERD: 6498)	2004	NERL	
WQ MYP APM 199	*Report on methods/indicators for diagnosing when biological impairments of rivers and streams are due to sediment loads (EERD) Water Quality MYP, APG 9, 2004*	2004	NERL	
APG 56 - Deliver to Program Offices and Regional Offices data and models for understanding national distribution of habitat and natural populations for spatially explicit ecological risk assessments		2005	ORD	Internal
	Develop habitat models for several vertebrate species across Nevada (ESD: 5447)	2005	NERL	

	Knowledge base of regional and national distributions and population trends for North American bird species	2005	NHEERL	
	Report on vegetation growth and community structure models that link to habitat based population models for predicting stressor effects on wildlife habitat	2005	NHEERL	
Sub LTG D2: Environmental managers are able to characterize and quantify relationships between stressors and responses for regulatory endpoints and valued ecological resources				2006
APG 57 - Environmental managers are able to characterize and quantify relationships between stressors and responses for regulatory endpoints and valued ecological resources		2006	ORD	Internal
	Report on the relationship between land cover at various scales to water quality and biological integrity in Little Miami watershed streams (EERD: 6600.1)	2003	NERL	
	Report examining the relationships between various classes and scales of Little Miami subwatershed landscape features on water chemistry measures, stream physical habitat and subsequently on the macroinvertebrate assemblage (EERD: 6600.1)	2003	NERL	
	Report examining the relationship between various classes and scales of landscape features on selected measure of in-stream biotic integrity in the Little Miami River watershed (EERD: 6600.1)	2004	NERL	
APM 248	Population models of stream fish response to hydrology and habitat alteration (ERD: 16606)	2004	NERL	
	Report employing classified hyperspectral imagery to conduct and compare multiple scalar land cover models for predicting water quality measures in the Little Miami River watershed (EERD: 6600.1)	2005	NERL	
	Report utilizing landscape metrics based on classified high-resolution hyperspectral imagery to predict selected measures of biological integrity in the Little Miami River watershed (EERD: 6600.1)	2006	NERL	
	Report utilizing multiple classes of landscape metrics based on classified high-resolution hyperspectral imagery and real-time stream monitoring to develop biologically-based criteria for stream assessment in the Little Miami River watershed (EERD: 6600.1)	2006	NERL	

	Reports on the development of species-specific multi-stressor models and the effects on wildlife population dynamics, including approaches for predicting risk to wildlife based on demographic and landscape alterations	2006	NCER	
APG - Risk assessors can use improved/new diagnostic indicators to determine causes of ecological impairment		2006	ORD	Internal
	Report on microbial biomarkers as indicators of stressor input and system recovery resulting from restoration activities	2004	NRMRL	
	Report on genomic analyses of exposure of fathead minnows to binary and ternary chemical mixtures (EERD: 6498)	2005	NERL	
	Report produced on development of molecular indicators of exposure to detect biologically relevant exposures to invertebrate organisms (*Daphnia* spp.) (EERD: 6498)	2005	NERL	
	Report on relationships of local scale risk factors to macroinvertebrate communities to landscape scale indicators in the mid-Atlantic (EERD: 6600)	2005	NERL	
	Report on predicting macroinvertebrate community condition using landscape indicators in the mid-Atlantic (EERD: 6600)	2006	NERL	
	Report on regional scale studies of molecular diagnostic indicators in fish from watersheds in the midwestern United States (EERD: 6498)	2006	NERL	
APG 58 - Deliver to the Program Offices and Regional Offices comprehensive chemical effects databases and species extrapolation models to estimate the effects of pesticides and other toxic chemicals on populations		2006	NHEERL	Internal
	Release of high quality toxicity database constructed for use in developing tiered wildlife risk assessments	2003	NHEERL	
APM 56	Develop a database framework of biochemical, physiological and anatomical parameters to support physiologically based species extrapolation models	2004	NHEERL	
	Establish toxicity databases and species extrapolation models as components of spatially explicit platform for tiered ecological risk assessments using representative classes of pesticides, toxic substances, and avian species	2006	NHEERL	
Sub LTG D3: Diagnostic methods exist that incorporate knowledge of and contributions of multi-stressor interactions				2006

APG - Risk assessors can attribute causes of impairment when caused by more than one stressor input		2007	NERL NCEA	Internal
WQ MYP	*Case study determining the causes of biological impairment in an urban setting with non-point source impacts so that states and tribes will have prototypes to facilitate completion of TMDLs (Water Quality MYP)*	*2006*	*NERL NCEA*	
WQ MYP	*Watershed Academy website training for causal analysis (Water Quality MYP)*	*2006*	*NERL NCEA*	
Sub-LTG D4: Protocols are available to regional, state and watershed scientists and managers that provide the scientific basis for determining the cause of observed ecological effects				2009
APG - Guidance on evaluating causes of impairments to aquatic systems are available to regional, state and watershed scientists and managers		2001	ORD	Internal
WQ MYP	*Complete Stressor Identification Guidance and Case Studies Water Quality MYP*	*2001*	*NERL NCEA*	
APG - Guidance on prioritizing ecological resources or problems for further attention based on vulnerability and exposure to multiple stressors		2008	ORD	Internal
	Guidance on prioritizing ecological resources or problems for further attention based on vulnerability and exposure to multiple stressors	2008	NERL NCEA	
APG - Methods are demonstrated that allow regional, state and watershed scientists to determine the causes of observed ecological effects		2009	ORD	Internal
	Parameters and the architecture for a Causal Analysis and Diagnosis Decision Information System (CADDIS), that helps users identify causes of biological impairment in the nation's waterbodies (NERL:EERD; NCEA)	2003	NCEA NERL	
APM 95	*Case study demonstrating the Stressor Identification Process that identifies the causes of biological impairment in the nation's waterbodies (EERD) Water Quality MYP, APG 16*	*2003*	*NERL*	
	Release Level 1 Causal Analysis and Diagnosis Decision Information System (CADDIS[1])	2005	NCEA NERL	
	Release Level 2 Causal Analysis and Diagnosis Decision Information System ((CADDIS[2])	2007	NCEA NERL	
	Release Level 3 Causal Analysis and Diagnosis Decision Information System (CADDIS[3])	2009	NCEA NERL	

APG - Guidance on causal evaluation is made available to regional, state and watershed scientists and managers		2009	ORD	Internal
	Guidance on causal evaluation is made available to regional, state and watershed scientists and managers (Proposed as a synthesis document)	2009	NCEA NERL	
Sub LTG D5: Characterize variability in unimpacted systems and in the present conditions and distinguish variability from change				2007
APG 59 - Provide Federal, State, and local resource managers with a means to more effectively determine long-term trends in the condition and vitality of Eastern U.S. stream ecosystems through measurements of changes in the genetic diversity of stream fish populations		2004	NERL	External
	Report on effectiveness of genetic indicator methods with recommendations for design of genetic monitoring studies of aquatic ecosystems (Completed in conjunction with 2002 NERL/EERD APM 66)	2003	NERL	
APM 249	A study of fish genetic diversity that demonstrates the power of this emerging technology for evaluating condition and vitality of biotic communities to Federal, state and local resource managers (EERD: 6497)	2004	NERL	External
APG 60 - Environmental managers can characterize the variability in the hydrology regimes for streams of the Mid-Atlantic region		2006	NERL	Internal
	A regional scale model for the Mid-Atlantic predicts stream hydrology in response to climate and vegetation patterns (ERD: 16606)	2005	NERL	
APG - Environmental managers are able to use new, cost-effective methods for detection of change and characterization of variability in natural systems		2004	NERL	Internal
Global MYP 227	*Report on geographic and seasonal variability of UV affecting human and ecological health (HEASD) - Global Climate Change MYP, APG 23, 2004*	*2004*	*NERL*	
APG - Deliver to the Program Offices and Regional Offices life- history and other biological data for estimating the effects of natural variation and habitat disturbance on the variability of natural populations		2007	ORD	Internal
	Joint EPA/Canadian Department of Fisheries and Oceans report developed on long-term genetic monitoring in fish based on 25-year Canadian tissue archive (EERD: 6497)	2004	NERL	
	Report on integration of genetic and landscape indicators in the Little Miami and Great Miami watersheds (EERD: 6497)	2005	NERL	

	Development of a species demographic and habitat requirement knowledge database to build and apply meta-population models that incorporate natural variation and habitat disturbance	2005	NHEERL	
	Report on demographic classifications for screening-level assessments	2005	NHEERL	
	Report on extinction and adaptation probabilities for several chironomid species in response to varying rates of change of environmental temperature (EERD: 6497)	2006	NERL	
	Deliver artificial intelligence interface to high quality biological databases to estimate species demographics and habitat attributes for organisms that are the focus of spatially explicit risk assessments	2007	NHEERL	
Sub-LTG D6: Observed patterns of stressors can be attributed to human activities and to natural change processes				2007
APG- Risk assessors can discriminate ecological effects caused by major natural factors from those induced by multiple anthropogenic point and non-point sources in streams, rivers, and upland ecosystems		2007	ORD	Internal
	Journal article quantifying relationships between human activities, stressors and ecological endpoints (e.g., for aquatic systems, quantify relationships between landscape indicators, water quality, habitat, stream biological condition; for terrestrial systems, quantify relationships between landscape indicators, forest productivity, and native species diversity) (NERL:ESD; NCEA)	2005	NERL NCEA	
	Report on methods/indicators for diagnosing when biological impairments of rivers and streams are due to habitat alteration (EERD: 6600)	2006	NERL	
	Journal article describing use of species-level empirical models to better discriminate ecological effects due to natural factors from those due to anthropogenic influence	2007	NCEA	

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Table 3 – Long-Term Goal: Forecasting

LTG 3 Environmental managers have the tools to predict multi-stressor effects on ecological resources to assess vulnerability and manage for sustainability

Sub-LTG F1: Characterize ecosystem processes and properties to support forecasting and evaluation of alternative management practices				2007
APG 153 Modelers have the necessary understanding of biogeochemical processes controlling nutrient cycling in watersheds to improve the scientific basis for risk management decisions		2006	ORD	Internal
	Publish RFA and fund up to 6 STAR grants relating to nutrient cycling and modeling	2001	NCER	
	Report on development and evaluation of new atmospheric dry deposition model that incorporates biogenic photosynthesis impacts	2001	NERL	
	Progress review/workshop to report on interim research findings	2003	NCER	
	Aquatic resources of the Mid-Atlantic Highlands: Analysis of communities, trout populations and management recommendations (ERD:)	2003	NERL	
APM 266	Evaluation of significant uncertainties in modeling nitrogen cycling to support multimedia management strategies (AMD: 3868)	2004	NERL	
WQ MYP	*Documentation of linked TMDL modeling system for nutrients (ERD) Water Quality MYP*	*2004*	*NERL*	
WQ MYP	*Report describing processes controlling oxidation state in subsurface environments and related controls on nitrogen fate (ERD)*	*2004*	*NERL*	
WQ MYP	*Report describing factors and processes controlling the fate of nutrients in streams (ERD)*	*2005*	*NERL*	
WQ MYP	*Demonstrate enhanced TMDL modeling system for nutrients (ERD) Water Quality MYP*	*2006*	*NERL*	
	Final STAR reports published on advances in nutrient cycling and modeling and their application to risk management decisions	2006	NCER	
APG 62 - Modelers have the necessary understanding of hydrologic processes in watersheds to improve the scientific basis for risk management decisions		2004	ORD	Internal

APM 43	Report on an object-oriented estuary model for the Neuse River to assist in risk management decisions	2004	NCER	
APM 44 APM 45 APM 46	Report(s) on the development of diagnostic and predictive watershed models and decision tools for resource managers and stakeholders	2004	NCER	
WQ MYP APM 284	*New sediment TMDL modeling protocol for instream processes (ERD) Water Quality MYP, APG 11, 2004*	*2004*	*NERL*	
	Risk managers and modelers can model distributed hydrologic and sediment processes that respond to changes in land use, vegetation and topography in selected watersheds of the Mid-Atlantic (ESD)	2004	NERL	
APG - Modelers have the necessary understanding of the behavior of pollutants in the atmosphere and in watersheds to predict ecosystems exposures		2008	NERL	Internal
	SPARC configured as a prototype processes constants generator for organic pollutants (completed models for ionization and tautomerization and prototype models for chemical hydrate formation, solution phase hydrolysis, and abiotic reduction in sediment suspensions) (ERD: 5549)	2002	NERL	
	A computational chemistry model will be available to predict binding of organic pollutants to composite environmental surfaces (ERD: 5549)	2003	NERL	
	A computational chemistry model will be available to estimate rate constants and reaction pathways for the reductive transformation of halogenated organics, nitroaromatics and aromatic azo compounds under specified redox conditions (ERD: 5549)	2005	NERL	
	A computational chemistry model will be available to estimate rate constants and reaction pathways describing the abiotic hydrolysis of carboxylic acid esters and organophosphorus compounds in soils and sediments (ERD: 5549)	2006	NERL	
	Assessment of annual nitrogen deposition (oxidized and reduced) to Tampa Bay to characterize the deposition and to provide guidance to the State of Florida on potential contributing sources (Bay Regional Atmospheric Chemistry Experiment) (AMD: 3868)	2007	NERL	
WQ MYP	*Demonstrate models to calculate and allocate TMDLs for pathogen indicators (ERD)*	*2007*	*NERL*	

WQ MYP	*Demonstrate models to calculate and allocate TMDLs for toxics (ERD)*	*2008*	*NERL*	
Sub-LTG F2: Ability to forecast human activities and natural processes that drive change in ecological systems				2010
APG 45 - Future scenarios analysis is demonstrated in the Mid-Atlantic region		2006	NERL	Internal
APM 17	Report describing the selection and application of alternative future scenarios for trade-offs analyses in the mid-Atlantic region (ESD: 5549 – 2003 APM delayed to 2004)	2004	NERL	
APG 63 - Future scenarios analyses are demonstrated in the Mid-Atlantic region and Region 4		2006	ORD	Internal
	Report on the complete assembly of landscape change models for assessing landscape conditions past, present and future	2002	NERL	
APM 250	Models for estimating impervious cover will be compared with remotely sensed data and applied to projections of population growth for Region 4 (ERD: 16506)	2004	NERL	
APM 276	Models for estimating impervious cover will be compared with remotely sensed data and applied to projections of population growth for the Mid-Atlantic region (ESD)	2004	NERL	
APM 275	Decision support tool for Mid-Atlantic that enables assessment of impacts associated with alternative land use, air deposition, and resource extraction scenarios as determined by client (ESD: 5449/8878)	2004	NERL	
	Decision support system that includes fish health and fish populations modeling as ecological endpoints for natural and anthropogenic stressors at multiple scales in the Mid-Atlantic region (ERD: 16606)	2005	NERL	
	Models for estimating lawn area and pesticide/nitrogen use compared with remotely sensed data and applied to population growth projections (ERD: 16506)	2005	NERL	
	Report on the effects of land use change on aquatic ecosystems in the Mid-Atlantic region using linked water resources and land use change models (ESD: 5442)	2005	NERL	
	A regional scale model for the Mid-Atlantic predicts stream hydrology in response to climate and vegetation patterns (ERD: 16606)	2005	NERL	

	Assess range changes of aquatic plants and animals accompanying climate, land use, and other changes in the Mid-Atlantic region using climate scenarios for the year 2050 (ESD)	2005	NERL	
	Report on future scenario methodology in the Mid-Atlantic that forecasts effects of projected changes in land use change, air deposition, spread of nonindigenous invasive species, climate change impacts on vegetation, and patterns of future resource extraction (ESD)	2006	NERL	
	A landscape model will relate imperviousness, flow magnitude and frequency, and possible impacts to physical habitats under alternative future landscape conditions and management practices (including resource extraction) in the Mid-Atlantic region (ESD: 5626)	2006	NERL	
Sub-LTG F3: Ability to extrapolate relationships and link model components across spatial and temporal scales				2006
APG 64 - Environmental managers can appropriately assess risks and evaluate outcomes of management decisions at different watershed scales		2006	NERL	Internal
APM 259	An ArcView extension tool is available to analyze landscape metrics at multiple watershed scales (ESD: 5447)	2004	NERL	
APM 251	Comparison of hydrologic responses at different watershed scales (ERD: 16606)	2004	NERL	
APM 268	Implementation in MIMS of statistical aggregation tools to construct seasonal and annual average air concentrations and deposition for application to multimedia problems (AMD: 3868)	2004	NERL	
APM 320	GIS modeling tool (ArcView extension) to target water body risks of TMDL exceedance for nutrients and sedimentation: the mid-Atlantic Region case study (ESD: 5447)	2004	NERL	
	Evaluation of stressor responses for aquatic resources at different watershed scales in the Mid-Atlantic region (ESD)	2005	NERL	
	Transfer landscape assessment technologies to Regional Offices so that they can conduct landscape assessments at many scales (ESD: 6821)	2006	NERL	
Sub-LTG F4: Ability to link or couple models to forecast effects and apportion influences across media and stressors				2015

APG 65 - Environmental managers can assess risks to ecosystems, using modeling tools that incorporate advanced models for atmospheric, land surface, and instream processes		2008	ORD	Internal
APM 84	Assessment of the sustainability fish communities and fish health in the Albemarle-Pamlico basin in the face of population and economic growth as a pilot project to define future needs/requirements for data/science/models (ERD)	2002	NERL	
	BASS scenarios and project databases specific to Canaan Valley watershed delivered (ERD: 16606)	2004	NERL	
APM 265	Demonstration of coupled deposition, plant, and soils models to improve dry deposition modeling (AMD:3868)	2004	NERL	
APM 274	Estimates of distribution and patterns of atmospheric nitrogen stressors including wet and dry concentrations and deposition flux available for selected geographic areas (ESD: 5450)	2004	NERL	
	Pesticide Root Zone Model (PRZM) leaching and vadose zone modules delivered (ERD:6519)	2005	NERL	
	Report on statistical methods for integrating monitoring network design, data analysis and model formulation to maximize the utility of process models	2005	NCER	
	Report(s) on new watershed classification systems published and evaluated for adoption by regional state water quality managers.	2007	NCER	
	Report(s) on the development of regional-scale stressor response models for environmental decision making	2008	NCER	
APG - Provide methodology and demonstrate its applicability for predicting cumulative impacts of multiple stressors on interacting wildlife populations and their habitats		2015	NHEERL	Internal
	Report on the efficacy of plant and animal community and ecosystem modeling approaches to assess risk from multiple stressors	2008	NHEERL	
	Provide an expanded version of the PATCH model capable of assessing interacting wildlife populations in dynamic communities	2010	NHEERL	
	Provide databases in support of models for predicting cumulative risks of multiple stressors to interacting wildlife populations	2012	NHEERL	

	Demonstrate risk assessment approaches to evaluate cumulative impacts of multiple stressors in a range of ecological communities	2014	NHEERL	
	Provide a synthesis of approaches to predict cumulative impacts of multiple stressors on interacting wildlife populations and their habitats	2015	NHEERL	
Sub-LTG F5: Ability to characterize source and magnitude of uncertainties and variabilities for pairwise and more complex relationships				2007
APG 66 - Statistical methods for sensitivity analysis/uncertainty analysis can be applied to stressor and ecosystem response models		2007	NERL	Internal
APM 269	MIMS framework support of uncertainty analysis to characterize multimedia processes and their effects (AMD: 3868)	2004	NERL	
Waste MYP APM 197	*Develop report on sensitivity and uncertainty analysis assessment for 3MRA modeling system (ERD) Hazardous Waste MYP, APG 40, 2004*	*2004*	*NERL*	
	Automated uncertainty analysis tool for HSPF (ERD: 16606)	2004	NERL	
Waste MYP	*Incorporation of sensitivity and uncertainty methods into 3MRA modeling system (ERD) Hazardous Waste MYP, APG nan, 2005*	*2005*	*NERL*	
Waste MYP	*Incorporate prototype approaches for variance-based methods of sensitivity and uncertainty analysis within 3MRA system (ERD) Hazardous Waste MYP, APG nan, 2007*	*2007*	*NERL*	
Sub-LTG F6: A decision support framework is available to support the long-term goal that includes models, modeling tools, and data access, manipulation, analysis, and visualization				2010
APG 67 - Environmental managers will have a prototype multimedia modeling system that enables them to perform site to small watershed scale contaminated site assessments, such as those addressed by RCRA, Superfund, CAA, and CWA		2004	NERL	Internal
Waste MYP APM 36	*Deliver science-based enhancements to the 3MRA multi-media modeling system to support OSW's regulatory-based national risk assessments and the related conduct of site-specific risk assessments that naturally follow upon the implementation of national regulations B Hazardous Waste MYP, APG 22, 2003*	*2003*	*NERL*	
Waste MYP APM 200	*Perform comparative model assessment of 3MRA modeling system at selected sites and prepare report (ERD) Hazardous Waste MYP, APG 40, 2004*	*2004*	*NERL*	

APG - Federal, State and local resource managers will have a prototype multimedia modeling system to evaluate anthropogenic impacts and natural variations on fish communities at watershed and basin scales		2010	ORD	Internal
	MIMS User's Manual (AMD: 3868)	2003	NERL	
	Implementation of initial MIMS model evaluation capabilities (AMD:3868)	2005	NERL	
	Report demonstrating the application of the geographically-based system for evaluating management alternatives in the Mid-Atlantic	2008	NRMRL NERL	
	Management alternatives handbook for watershed-level assessments (Synthesis Document)	2010	NCEA	
Sub-LTG F7: Regional, State, and watershed scientists and managers can anticipate threats to ecological resources using scientifically sound forecasts of ecological condition				2010
APG - Regional, State, and watershed scientists and managers in the Mid-Atlantic region can anticipate threats to ecological resources using scientifically sound vulnerability and cumulative exposure assessments.		2008	NERL	Internal
	Vulnerability assessment for Mid-Atlantic streams and forests	2002	NERL	
	Comprehensive vulnerability assessment for the mid-Atlantic region (ESD: 8877)	2006	NERL	
APG - Managers are provided with guidance and tools that facilitate estimation of environmental risks due to invasive species		**2010**	**ORD**	**Internal**
	Methodology for prioritizing risks from invasive species in the Mid-Atlantic	2005	NCEA	
	Investigate the effects of plant invasions on Laurentian Great Lakes wetlands (ESD: 5442)	2006	NERL	
	Guidance on assessing risks from invasive species	2006	NCEA	
	Report(s) on invasive species to include analysis of susceptible environments/habitats, spatial patterning and methods of control	2006	NCER	
	Risk Assessment of invasiveness for species in the Great Lakes (External Peer Review Draft)	2008	NCEA	

	Report on approaches and models to predict the spread of aquatic invaders and rank the vulnerability of aquatic systems to invasion	2008	NHEERL	
	Report on model to predict the impact of invasive species on native species and ecosystem functions in estuarine and freshwater systems, including impairment of designated uses for a water body and the flux of conventional and toxic pollutants into estuarine and freshwater systems	2010	NHEERL	
APG - Guidance on anticipating threats to ecological resources using assessments of vulnerability, cumulative risk, and future scenarios is made available to regional, State and watershed scientists and managers		2010	ORD	Internal
	Report(s) on social, economic, and technological trends that will generate future environmental risk	2005	NCER	
	Report(s) on advancements in statistical methodologies for use in ecological risk assessment	2005	NCER	
	Methods for determining how human activities, for which mitigating management treatment options can be considered, impact ecological condition	2005	NCEA	
	Guidance on conducting assessments of vulnerability and cumulative risk that allow managers to better anticipate threats to ecological resources.	2008	NERL NCEA	
	Guidance on future scenario analysis (Synthesis document)	2008	NERL NCEA	
Sub-LTG F8: Protocols are available to regional, State and watershed organizations that provide the scientific basis for predicting the ecological benefits of different management alternatives				2010
APG 61 - Deliver to Program and Regional Offices a computerized GIS for conducting spatially-explicit ecological risk assessments		2004	NHEERL	Internal
APM 57	Deliver Windows version of PATCH model with documentation and example analysis	2004	NHEERL	
APG - Deliver to Program Offices and Regional Offices an updated GIS with databases and models for conducting spatially-explicit ecological risk assessments		2010	ORD	Internal
	Provide PATCH demonstration model as a platform for assessing the cumulative risks to selected bird species from habitat alteration and chemical stressors in the Pacific Northwest	2005	NHEERL	

	Develop landscape exposure model data export function to support PATCH	2006	NERL	unfunde d
	Develop landscape exposure model data import interface with PATCH to facilitate prediction of pesticide risk	2006	NHEERL	
	Report on the efficacy of population modeling approaches to assess risk from multiple stressors	2007	NHEERL	
	Provide a generally applicable, linked GIS-biogeochemical-hydrologic model for predicting landscape scale changes in terrestrial habitats in response to stress	2007	NHEERL	
WQ MYP	*Produce landscape indicator "tool box" to forecast impacts from pesticide use strategies (ESD) - Water Quality MYP APG 2008*	*2008*	*NERL*	
	Deliver revised PATCH II model for Windows with generalized life history module and general stressor module	2008	NHEERL	
	Provide user interface and visualization programs for PATCH and habitat models	2009	NHEERL	
	Report on calibration of PATCH and GIS-biogeochemical-based habitat models for the Great Plains region	2010	NHEERL	
Sub-LTG F9: Protocols are available to regional, State and watershed organizations that provide the basis for conducting predictive community-level risk assessments				2015
APG - Deliver to Program and Regional Offices a GIS with databases and models for conducting predictive community-level risk assessments		2015	NHEERL	Internal
	Report on the efficacy of community and ecosystem modeling approaches to predict risk from multiple stressors	2008	NHEERL	
	Provide modeling module in PATCH for predicting risk of chemical stressors to communities and ecosystems	2010	NHEERL	
	Provide regional databases of aquatic and terrestrial communities	2010	NHEERL	
	Provide species sensitivity distributions for aquatic communities	2011	NHEERL	
	Report on community-level risk assessment of chemical stressors for Midwest aquatic communities	2012	NHEERL	
	Provide species sensitivity distributions for terrestrial bird communities	2012	NHEERL	

	Report on community-level risk assessment of chemical stressors for Midwest bird communities	2013	NHEERL	
	Report on community-level risk assessment of chemical stressors for estuarine communities	2014	NHEERL	
	Report on GIS methodology for risk assessment of multiple stressors for aquatic and terrestrial ecosystems	2015	NHEERL	

Note: NERL APMs include information to identify specific organizational branches responsible for the research effort and research task numbers.

Table 4 – Long-Term Goal: Restoration and Management				
LTG 4 - Managers have scientifically defensible methods to protect and restore ecosystem condition				
Sub LTG R1: Watershed managers have state-of-the- science field-evaluated tools, technical guidance, and decision-support systems for selecting, implementing, and evaluating cost-effective and environmentally-sound approaches to restore ecosystem services as part of watershed management				2010
APG 27 - Environmental managers will have new approaches for prioritizing, implementing, and evaluating watershed rehabilitation efforts for selected watersheds in the U.S.		2004	ORD	
	Final technical reports and journal articles from STAR investigators describing new monitoring and assessment approaches and integrated decision support tools for use by watershed managers to prioritize, plan, and implement cost-effective projects to restore stream habitat and biota.	2003	NCER	
APM 7	Identifying Great lakes coastal wetland impairment due to invasive exotic species: A remote sensing approach (ESD: 5447)	2003	NERL	
	Papers describing a probabilistic approach to soils and ground-water vulnerability	2003	NRMRL	
APM 242	Draft assessment on the vulnerability of forests and small streams in the mid-Atlantic region (ESD:5549; FY03 APM 242)	2004	NERL	
APG 28 - Environmental managers will have an evaluation of the effectiveness of riparian buffers as a means to restore and maintain water quality within the Mid Atlantic Region of the US		2004	ORD	Internal
	Report describing the effectiveness of selected riparian zone restoration activities for restoring water quality	2003	NRMRL	
APG 68 - Environmental managers will be better able to evaluate the potential benefits of riparian zone restoration for controlling nutrient transport to surface waters		2004	NRMRL	Internal
	Hydrogeologic foundations in support of ecosystem restoration: Data management application and database	2003	NRMRL	
	Report on the framework for hydrogeologic controls (EPA/600/R-02/008 January 2002, Hydrogeologic Framework, Ground-Water Geochemistry, and Assessment of Nitrogen Yield from Base Flow in Two Agricultural Watersheds, Kent County, Maryland)	2002	NRMRL	

	Report on the functions of riparian zones and strategies for their management	2002	NRMRL	
APM 130	Report identifying cost-effective risk management options to manage watershed susceptibilities and impacts from nitrogen loadings	2004	NRMRL	
APM 134	Report on the effects of changing the amounts and ratios of N and P on water quality in receiving water bodies	2004	NRMRL	
APG - Environmental managers will have technical guidance for implementing and evaluating projects to restore riparian zones in a watershed management context		2005	ORD	External
	Website for the publication of issue papers and other documents as a resource to guide development of ecosystem restoration needs, issues, and practices.	2003	NRMRL	
	Final STAR reports on 1) Opportunities and constraints for riparian restoration in the Willamette River basin and 2) Riparian reforestation in an urbanizing watershed: Effects of upland condition on instream ecological benefits	2002	NCER	
	Model of invasibility and impact on riparian buffer restoration	2003	NRMRL	
	Report on the effectiveness of riparian restoration to reduce nitrogen loading to streams	2003	NRMRL	
	Papers describing engineered methods of stressor attenuation within constructed wetlands under wet weather flow conditions	2003	NRMRL	
	Report on wetland restoration for improving water quality in riparian zones	2004	NRMRL	
	Technical resource guide (a collection of Advances in Restoration Sciences Issue Papers) for restoration of riparian zones to manage and restore water quality	2005	NRMRL	External
APG - Environmental managers have tools to determine restoration needs and priorities based on biological status and trends data		2006	NRMRL	Internal
	Report on the utilization of remote sensing techniques for woody species composition and density as ecosystem restoration and management tools.	2005	NRMRL	
	Bayesian foundations and tools for prioritizing watersheds and ecosystems for restoration	2006	NRMRL	
APG - Environmental managers have tools to design, select, implement, and evaluate watershed restoration methods for aquatic resources in a watershed context in the Mid Atlantic Region		2007	ORD	Internal

	Report on restoration of hydrocarbon contaminated salt marshes	2002	NRMRL	
	Final STAR report on applying the Patuxant and Gwynn Falls (MD) landscape models to whole watershed restoration	2003	NCER	
APM 135	Decision support tool for lake/reservoir based on system assimilative capacity	2004	NRMRL	
WQ MYP	*Systems analysis tools for establishing optimal risk management of watersheds Water Quality MYP*	*2005*	*NRMRL*	
	Report on the effectiveness of specific stream restoration techniques to improve water quality in urban streams	2006	NRMRL	
	Guidelines for watershed management	2007	NRMRL	
APG - Environmental scientists have an evaluation of the effectiveness of activities to restore aquatic ecosystems in the western United States		2008	ORD	Internal
	STAR final report on developing methods and tools for watershed restoration: design implementation and assessment in the Willamette basin, Oregon	2003	NCER	
	Report on monitoring and modeling of the impact of changes in hydrologic regime on ecosystem functions in the Great Basin	2008	NRMRL	
APG - Three pilot restoration projects for developed and partially developed watersheds with different endpoints of societal value demonstrate the efficacy of the guidance developed by this program		2008	NRMRL	Internal
	Report on three pilot restoration projects for developed and partially developed watersheds with different endpoints of societal value *(STAR RFA will address this, based on existing projects already in place)*	2008	NRMRL NCER	
APG - Demonstrate proof-of-concept integrated assessments for allocation of environmental management resources within the context of socioeconomic factors and ecological integrity		2010	NHEERL	Internal
	Report on comparisons of emergy audits of seven Northeast/Midwest States (AED)	2005	NHEERL	
	Report on ecologically-based spatial unit model for evaluating management alternatives within the context of relevant socioeconomic factors and ecological integrity (AED)	2006	NHEERL	
	Deliver software to support environmental management decisions within watersheds (AED)	2007	NHEERL	
	Report on the comparison of ecological and economic evaluation as a basis for environmental decision making (AED)	2008	NHEERL	

	Report on methods for synthesis of ecological and economic analysis as an approach to making integrated resource management decisions (AED)	2009	NHEERL	
	Demonstration of synthesis of ecological analysis and economic analysis as an approach to making integrated resource management decisions (AED)	2010	NHEERL	

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